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HOW IT WORKS

AMAZING ELECTRICTY

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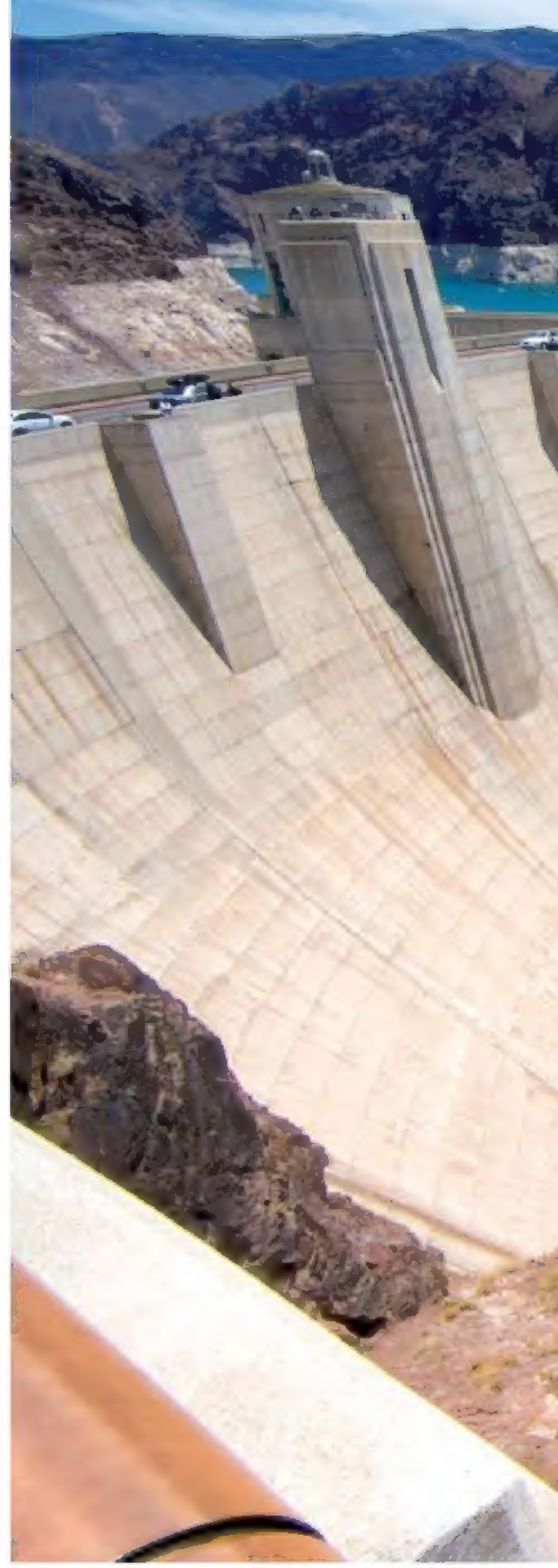

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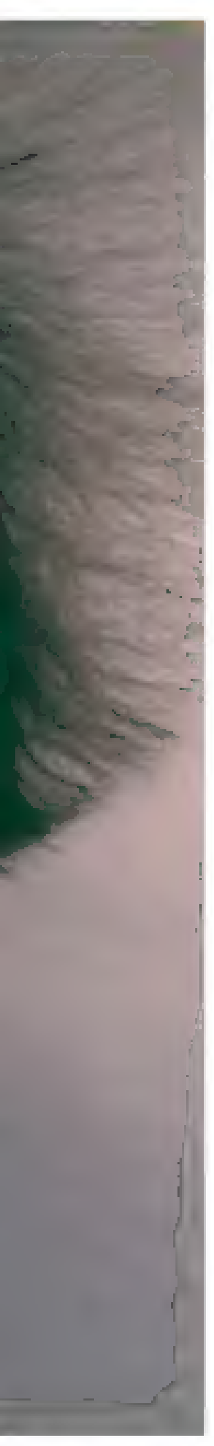
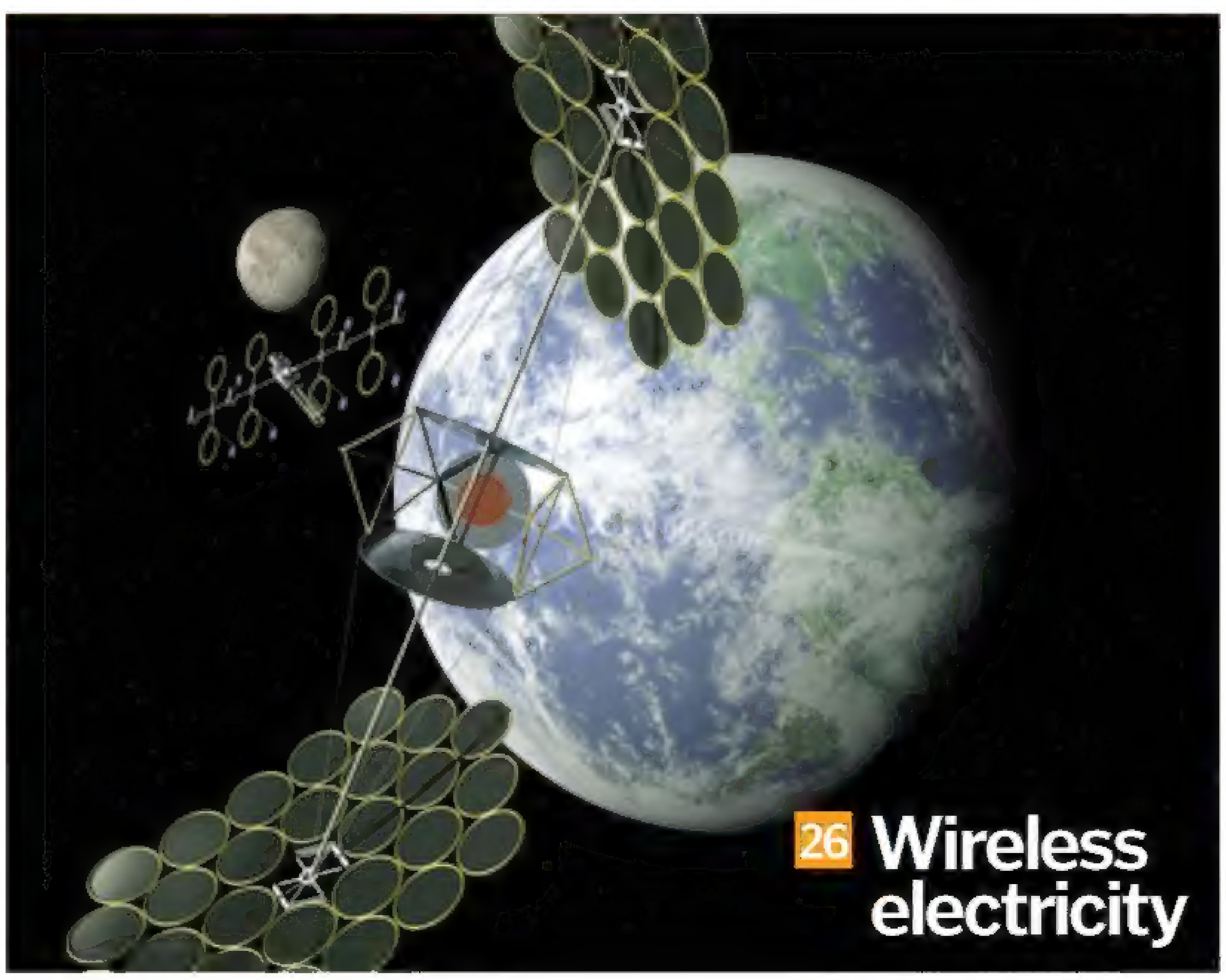




> "Materials like wood, glass, ceramics and cotton all have electrons"

Electricity explained

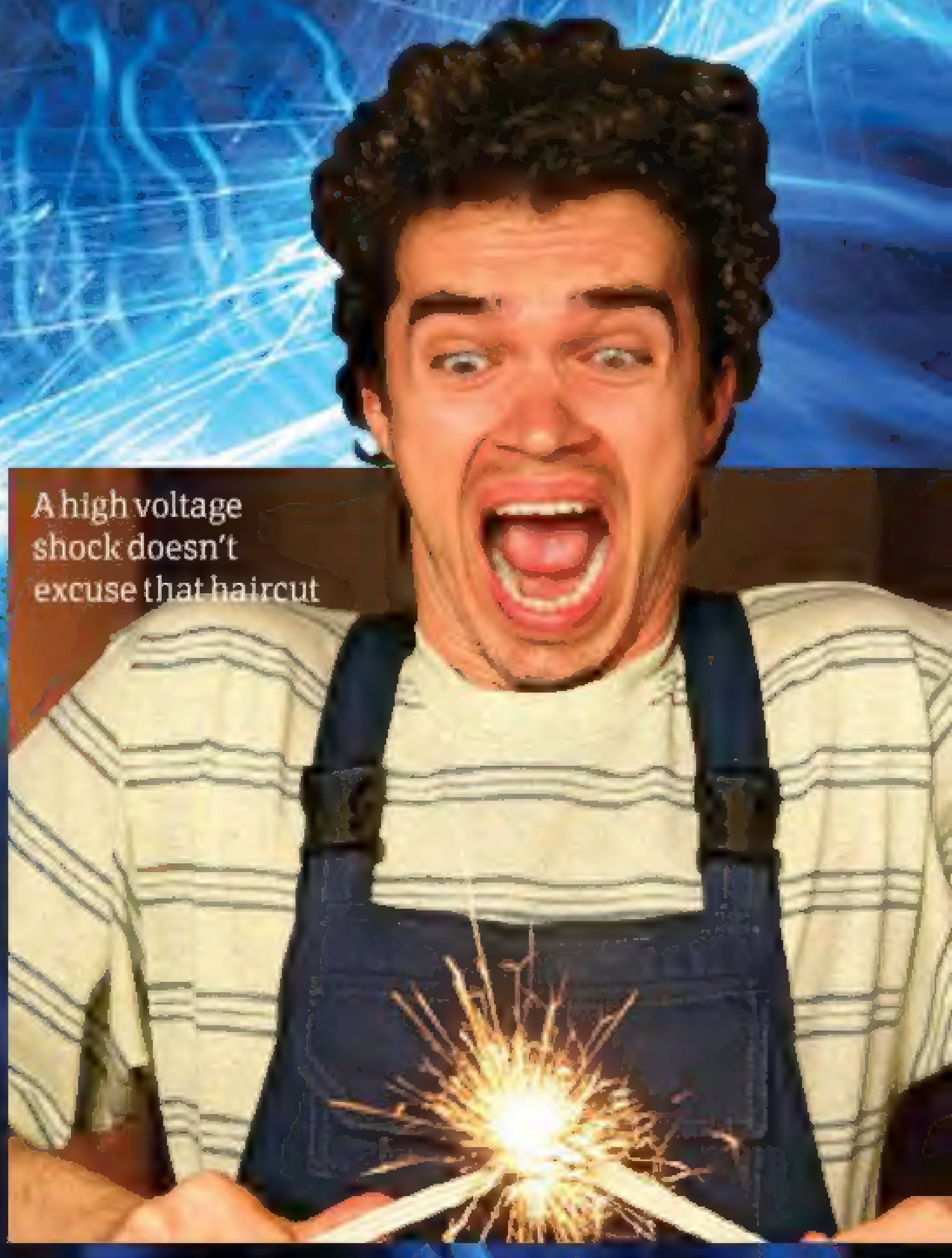
Learn some shocking facts behind the everyday energy we take for granted

Many people think of electricity as something you buy from the power companies, but as well as coming out of the wall socket, electricity is one of the many ingredients that make up the universe. Read on to find out why electricity occurs, how it behaves and how it reaches your home.

Everything in the universe is made of minuscule atoms and these atoms consist of a nucleus orbited by one or more electrons. These electrons carry a negative charge while the nucleus is positively charged.

We're all familiar with the effects of static electricity. We are not often aware of electricity around us as the positive and negative charges usually balance. When certain objects touch, however, electrons can jump between them. For instance, when you rub a balloon against your hair electrons will jump across to the balloon giving the balloon stationary negative charge or static electricity. Static electricity relies on electrons not being able to move around easily. Materials like wood, glass, ceramics and cotton all have electrons that like to stick with their atoms and because the electrons don't move the materials can't conduct electricity very well.

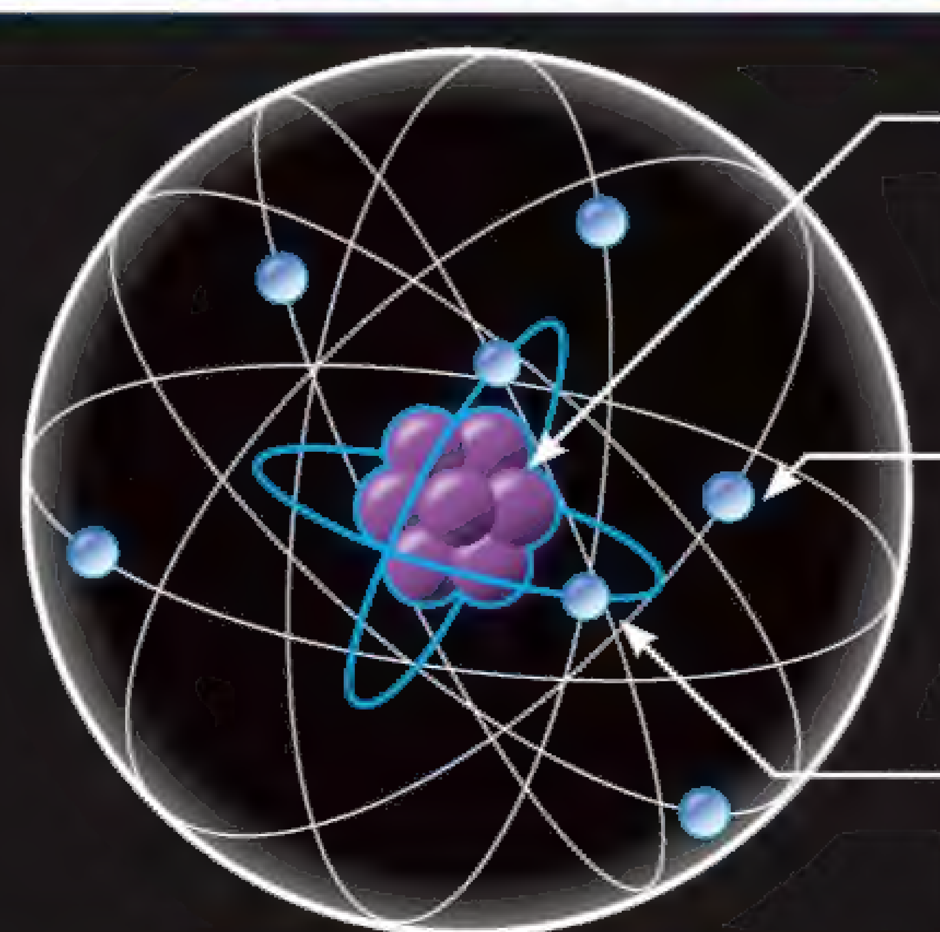
In most metals, electrons can move freely to form an electric current. When charges move, current electricity is formed and this is the power that drives much of the contemporary world. Current can be measured by the amount of charge passing a fixed point each second.



A high voltage shock doesn't excuse that haircut

Inside an atom

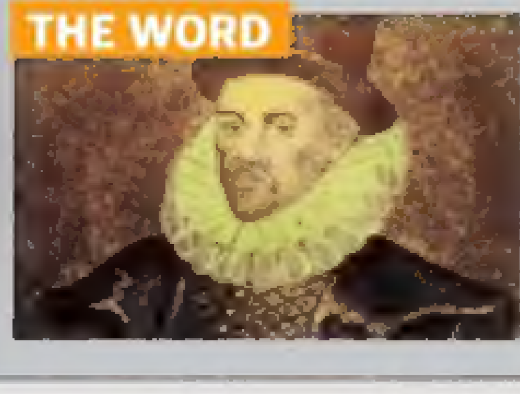
Atoms are held together by electricity. The positive nucleus attracts the negative electron. The two cancel each other out so the atom has no electric charge



1. The nucleus
This is at the centre of the atom and is positively charged.

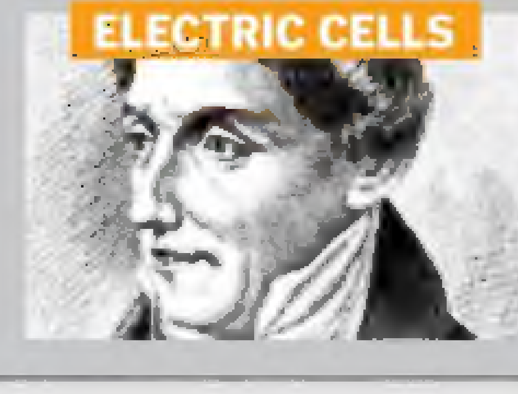
2. Negative charge
Each electron is negatively charged.

3. Electrons
Electrons orbit the nucleus.



1. William Gilbert 1544-1603
Scientist and physician to Queen Elizabeth I, he invented the term and was the first to describe the earth's magnetic field.

2. Benjamin Franklin 1706-1790
Flew a kite with a metal key attached into a thunderstorm to prove that lightning is a form of electricity.

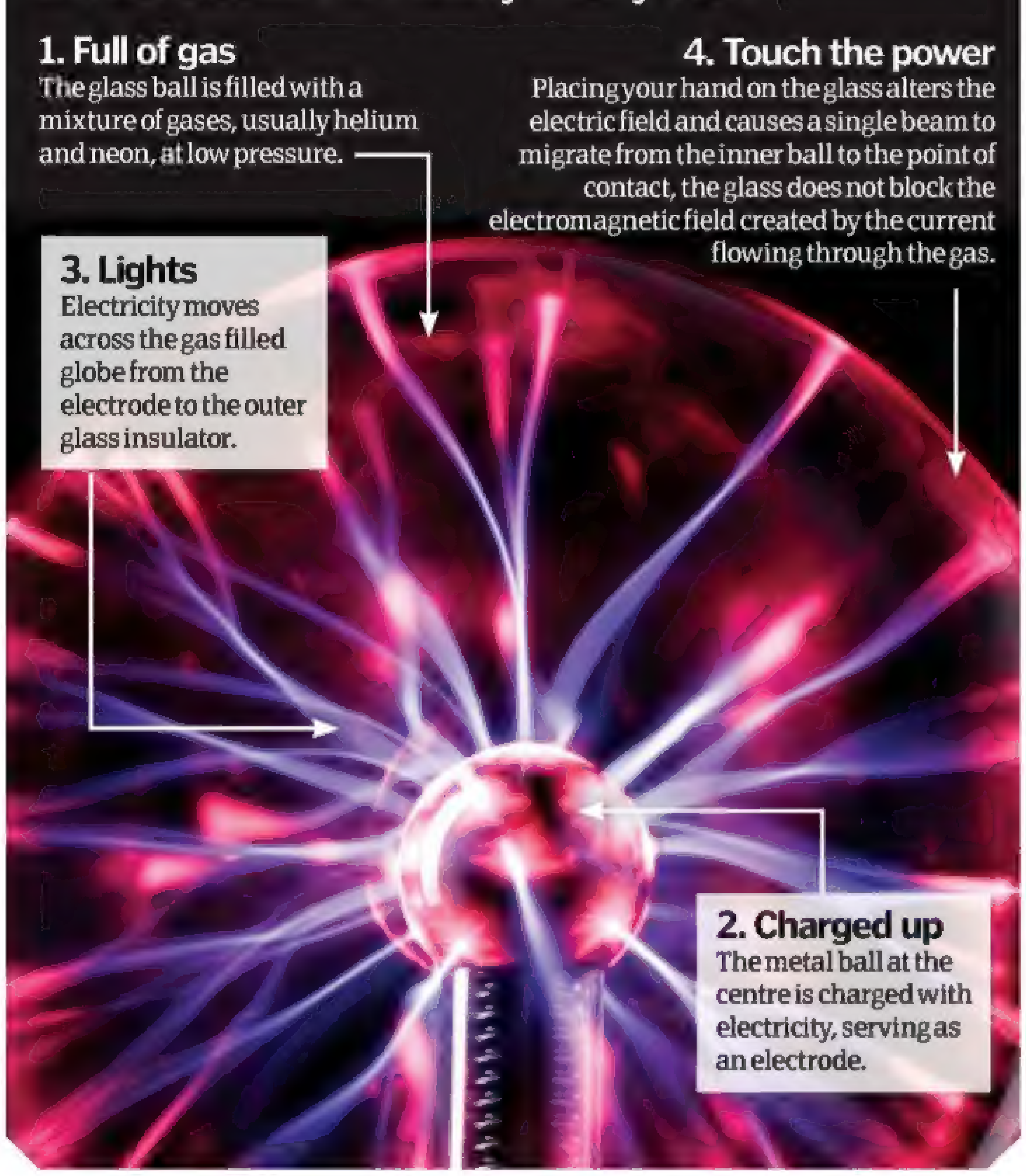


3. Alessandro Volta 1745-1827
This Italian scientist's experiment using soaked paper in salt water, zinc and copper created the first electric cell.

DID YOU KNOW? *The word 'electricity' is derived from the Greek word for amber, elektron*

Plasma balls – static incarnate

They went out of fashion in the 1980s but still demonstrate electricity really well

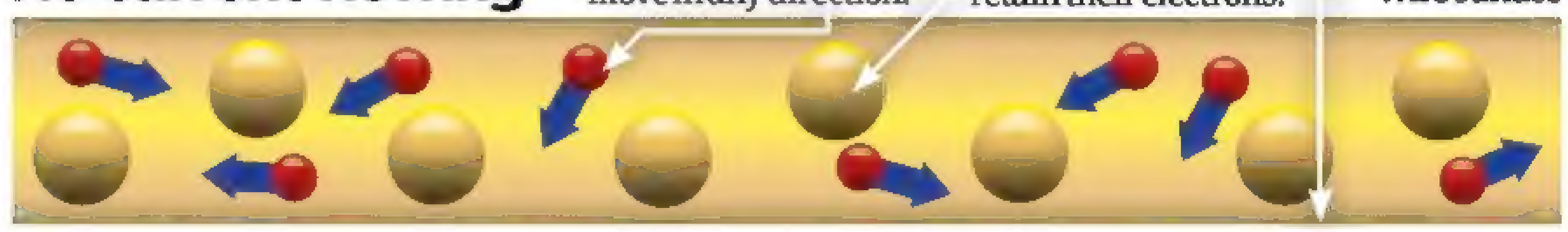


Conductors

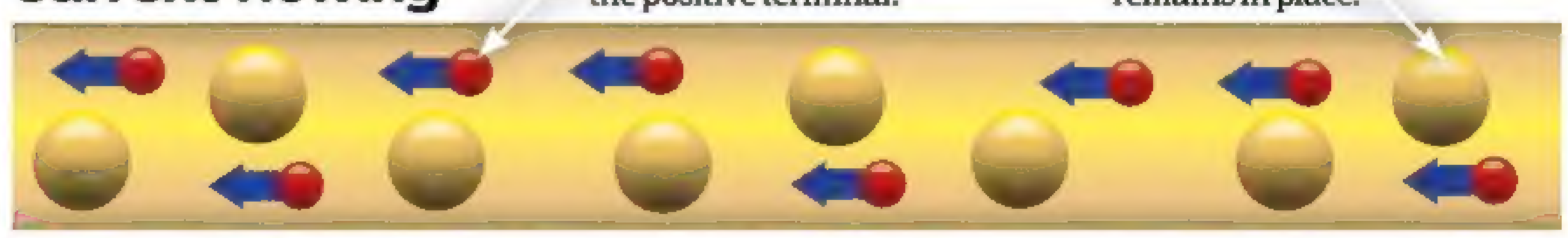
Very simply, a conductor is a material that allows electric charge to pass along it as a current. Metals make good conductors as the electrons of their atoms are loosely bound and free to move through the material. For instance, in copper the electrons are essentially free and strongly repel each other. Any external influence that moves one of them will be replicated through the material.

A superconductor is a material with no resistance at all to the flow of current when kept below a certain temperature. For most such materials, the critical temperature is below about 30 degrees Kelvin (30 degrees Celsius above absolute zero).

No current flowing



Current flowing



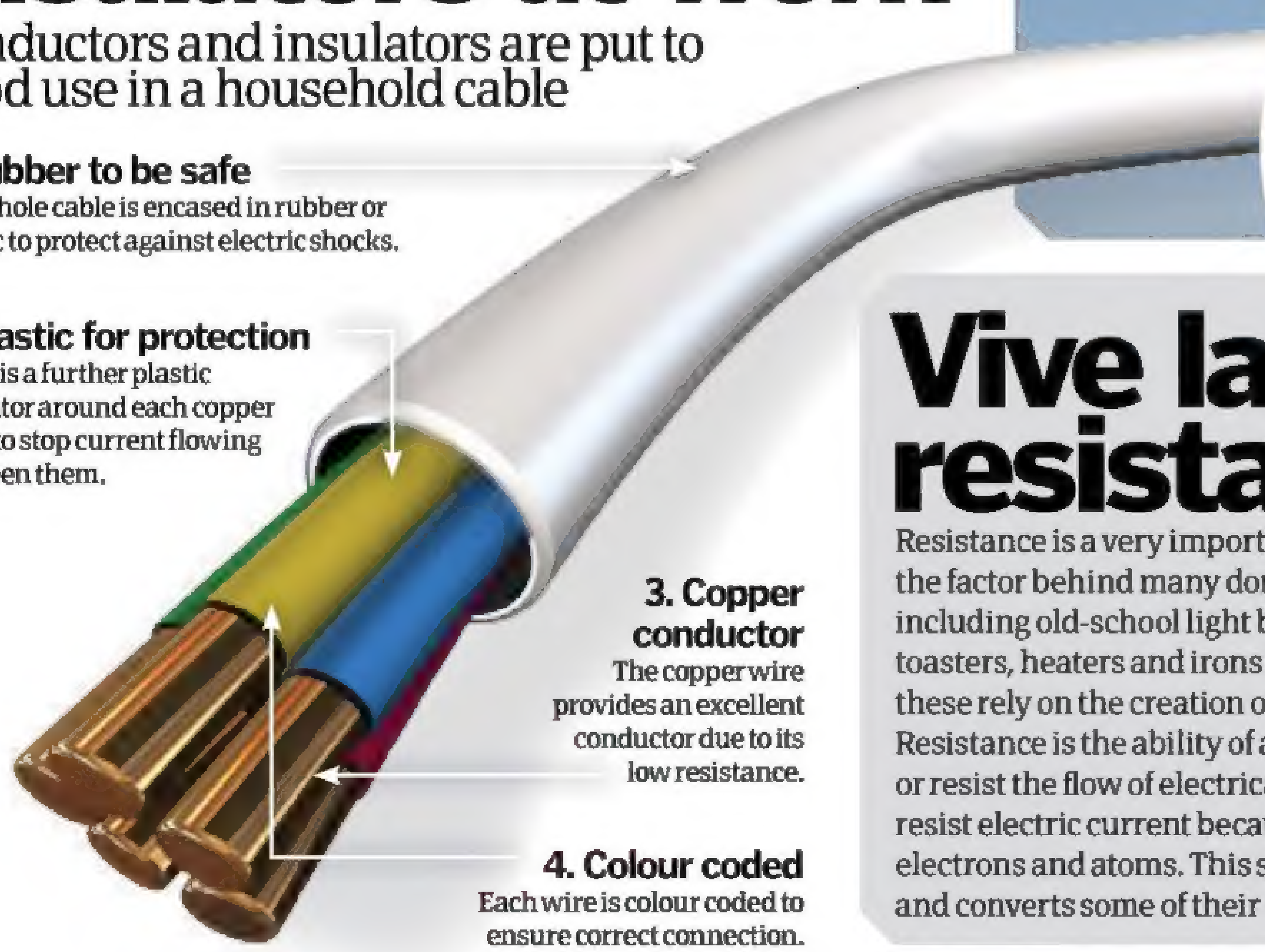
Insulators

Insulators are materials that have the exact opposite effect on the flow of electrons. Their atoms have tightly bound electrons which are not free to roam around. That said, insulators can still play an important role in the flow of electricity by protecting us from the dangerous effects of a current flowing through conductors. If the voltage is high enough an electric current can be made to flow through a material that is not a good conductor, like the human body. The function of our hearts can be affected by an electric shock and the heat generated by the current can cause burns.


The ceramic insulators on this pylon are there to prevent this worker becoming toast

Conductors and insulators at work

Conductors and insulators are put to good use in a household cable




An electric current passes through a thin filament, heating it so that it produces light

Vive la resistance

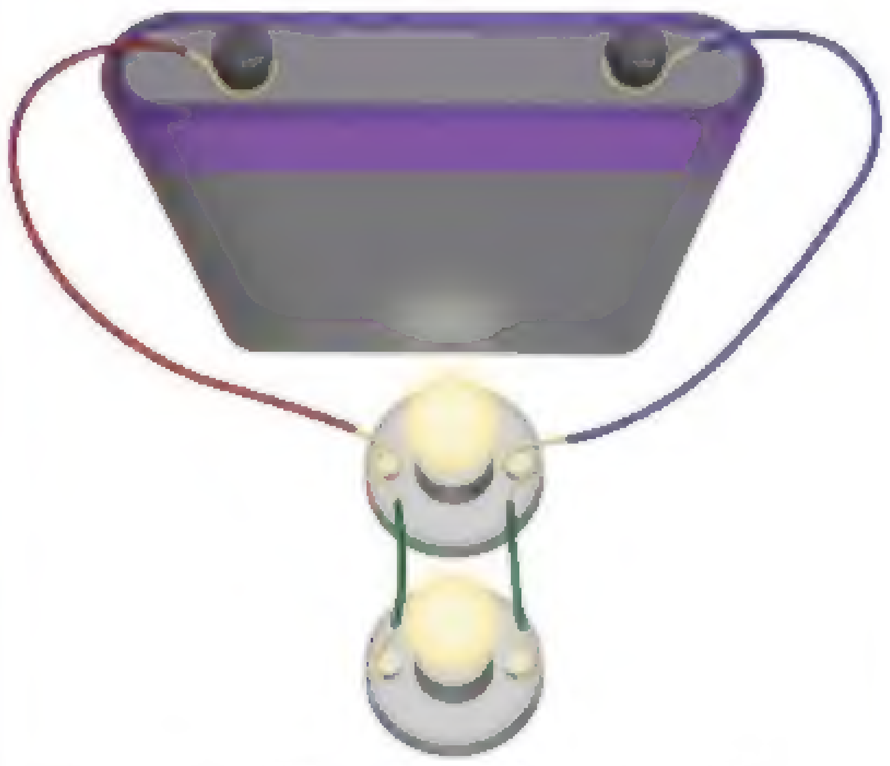
Resistance is a very important property, it's the factor behind many domestic appliances including old-school light bulbs, kettles, toasters, heaters and irons to name a few. All these rely on the creation of heat energy. Resistance is the ability of a substance to prevent or resist the flow of electrical current. Materials resist electric current because of a collision between electrons and atoms. This slows the electrons down and converts some of their energy to heat energy.

"Electricity can't do a lot of work without circuits as these provide a path for the electricity to flow around"

Circuits

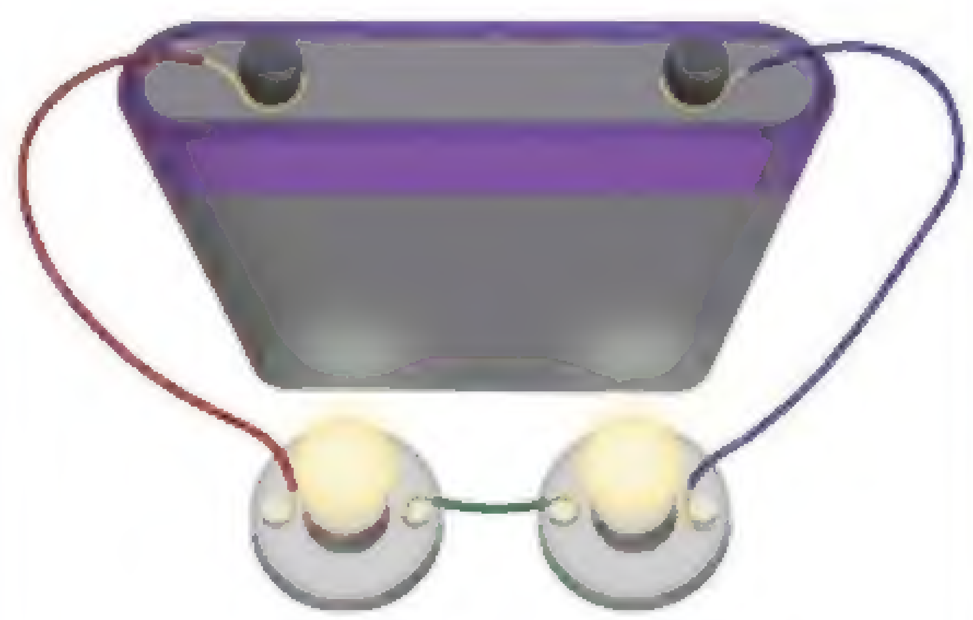
Putting electricity to work all over the world

Now that we've explained where electricity comes from it's time to look at some of the work it can do for us. Electricity can't do a lot of work without circuits as these provide a path for the electricity to flow around. Circuits include devices such as resistors, which control the flow of voltage, or difference in electrical charge, and capacitors, which store electrical charge and come in one of two types, series and parallel.



Parallel circuits

In a parallel circuit there is more than one pathway between its beginning and end. Since the electricity has more than one route to take, the circuit can still function should one component fail. This means that parallel circuits are much less prone to failure than the series variety. For this reason parallel circuits are the kind you will find in most everyday applications such as domestic appliances and household wiring.



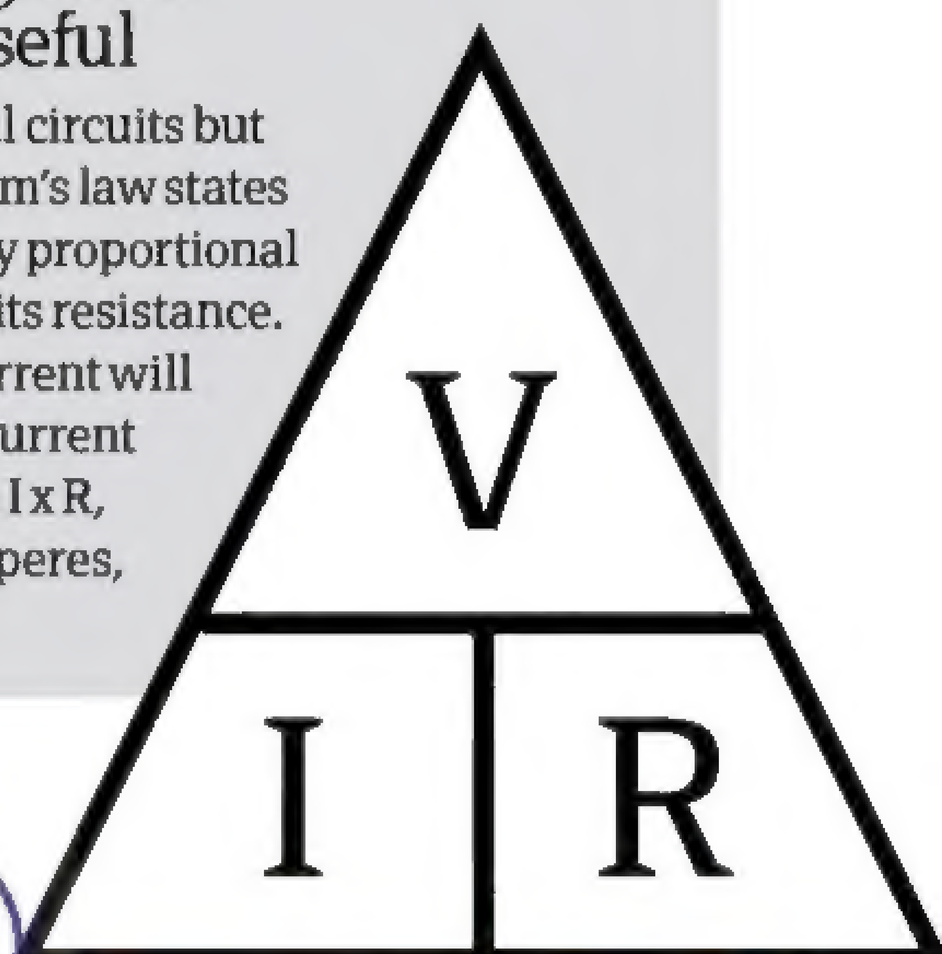
Series circuits

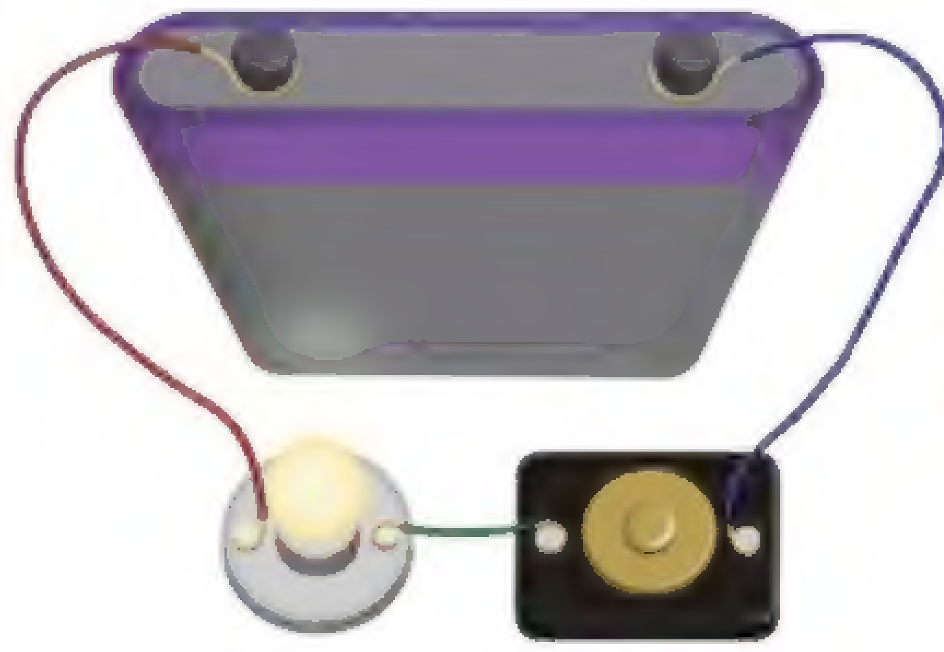
A series circuit has more than one resistor and only has one path for the charges to move along. A resistor is anything that uses electricity to do work (in this case, light bulbs) and the electric charge must move in series from one resistor to the next. If one of the components in the circuit is broken then no charge can move through it. An example of a series circuit is old-style Christmas lights, if one bulb breaks the whole string goes out.

Laws of circuits

Ohm's triangle; not as exciting as the Bermuda triangle but more useful

There are many laws that apply to electrical circuits but Ohm's law is one of the most important. Ohm's law states that an electrical circuit's current is directly proportional to its voltage and inversely proportional to its resistance. So, if voltage increases, for example, the current will also increase, and if resistance increases, current decreases. The formula for Ohm's law is V = I x R, where V = voltage in volts, I = current in amperes, and R = resistance in ohms.





Circuit control

The simplest electrical control is a switch. This simply breaks the circuit to stop the current flowing and this is most notably seen in domestic light switches. They may seem simple, but the most complex computers are made from millions of electronically controlled switches.

CIRCUIT JARGON

Current
The flow of an electric charge. Unit volt, symbol V.

Voltage
Or electrical potential difference, the force that drives the current in one direction. Unit ampere, symbol A.

Resistance
The opposition of an object to having current pass through it. Unit ohm, symbol Ω.

How electricity reaches your home

It's taken for granted that the light will come on when you hit the switch, here's how the power gets to your house

1. Coal or nuclear
Coal is burnt at the electricity plant to generate steam. Nuclear power stations use a different method, and so do hydroelectric plants.

2. Generation X
Be it nuclear, coal-fired or hydro a turbine spins a huge magnet inside a copper wire. Heat energy converts to mechanical energy which then converts to electrical energy in the generator.

3. Danger! High voltage!
The electricity then flows though heavily insulated wires to a step-up transformer. This raises the pressure so it can travel long distances over the grid. It's raised as high as 756,000 volts.

4. Transform it
The electricity then runs along the power lines until it reaches a substation. This lowers the pressure to around 2,000-13,000 volts.

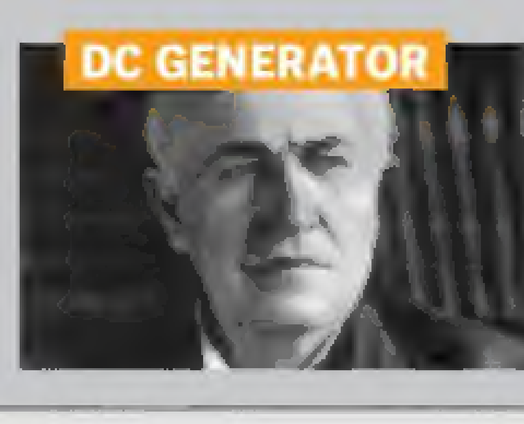
5. Pylon it up
The current continues along the lines to another transformer, either a pole transformer or an underground box, and pressure is lowered again to between 120 and 240 volts.

6. Service with a spark
The next stop is the service box at your home. Here your meter will measure how much power you use. Wires then take the electricity around your home powering your lights and everything else.

ELECTRIC MOTORS

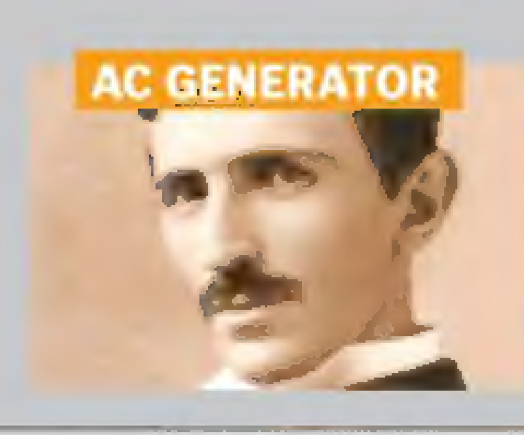
1. Michael Faraday 1791-1867
Faraday discovered that when a magnet is moved inside a coil of copper wire, a tiny electric current flows through the wire.

DC GENERATOR



2. Thomas Edison 1847-1931
Edison built a DC (direct current) electric generator in America. He later provided all of New York's electricity.

AC GENERATOR



3. Nikola Tesla 1856-1943
Developed an AC motor and a system of AC power generation. This became the established power supply in the USA.

DID YOU KNOW? *Edison saw Tesla's system as a threat to his DC supply and spread stories that it wasn't safe*

Electricity in your home

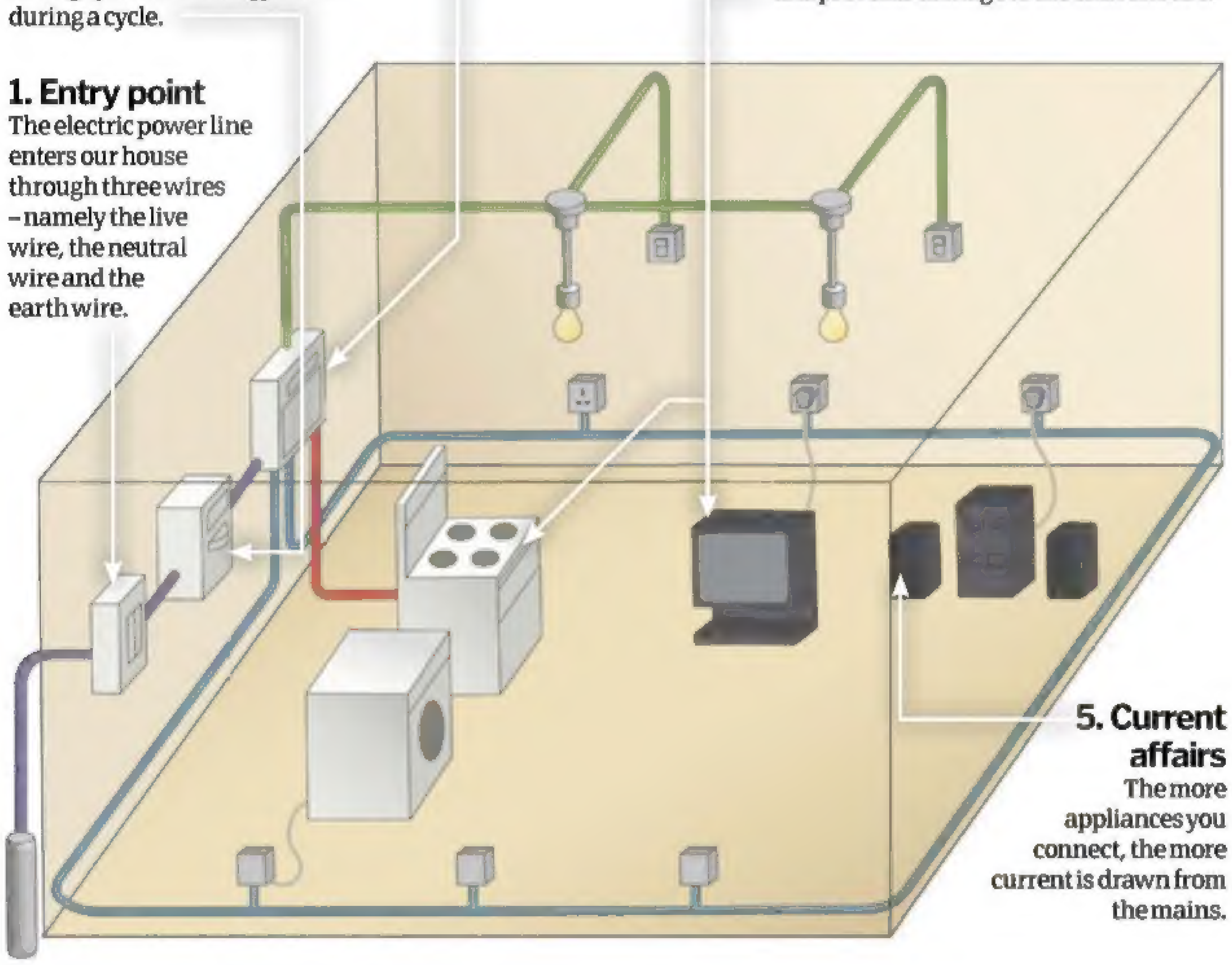
Once electricity reaches your home, how does it get around?

2. Electricity meter
Electricity meters are typically calibrated in billing units, the most common one being the kilowatt hour. Periodic readings of electric meters establishes billing cycles and energy used during a cycle.

3. Distribution box
This contains the main switch and fuses for each circuit.

4. Appliances of science
Domestic appliances are connected in parallel. In a parallel circuit even if there is a fault or short-circuiting in any one line, the corresponding fuse blows off, leaving the other circuits and appliances intact and prevents damage to the entire house.

1. Entry point
The electric power line enters our house through three wires – namely the live wire, the neutral wire and the earth wire.



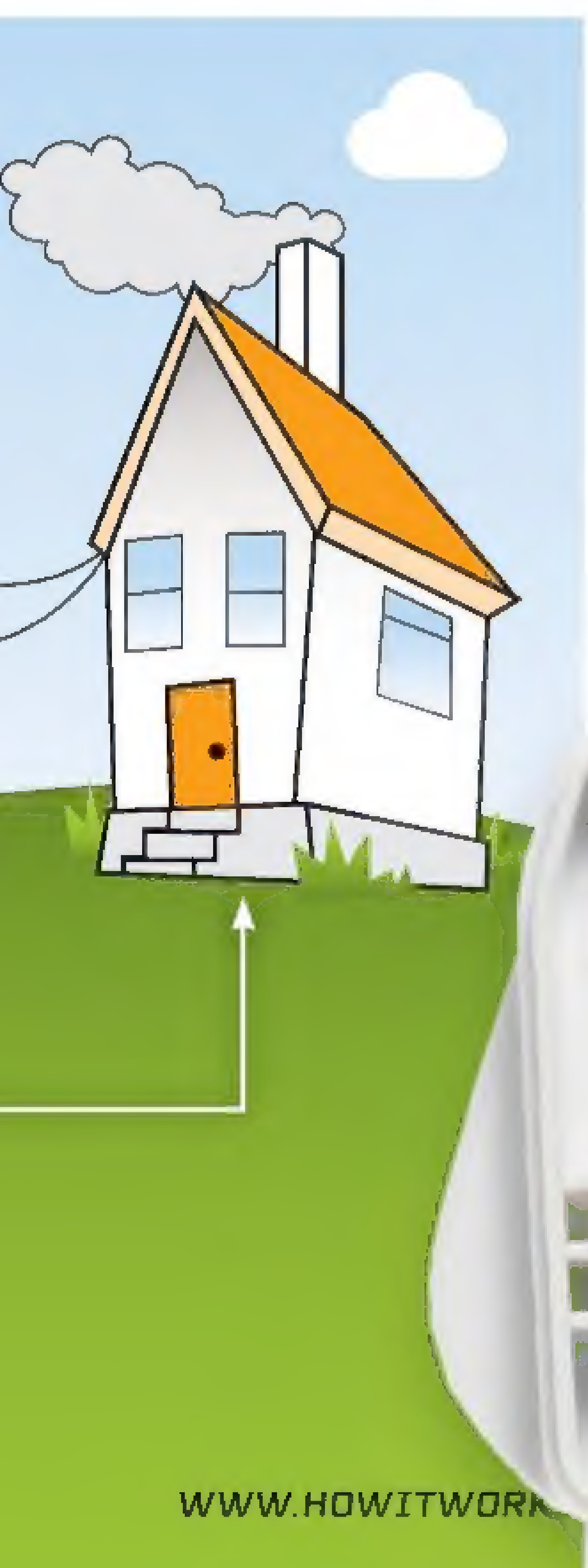
5. Current affairs
The more appliances you connect, the more current is drawn from the mains.

The only thing shocking about AC/DC these days is Angus Young's shorts!

© Weathermango

All about AC/DC

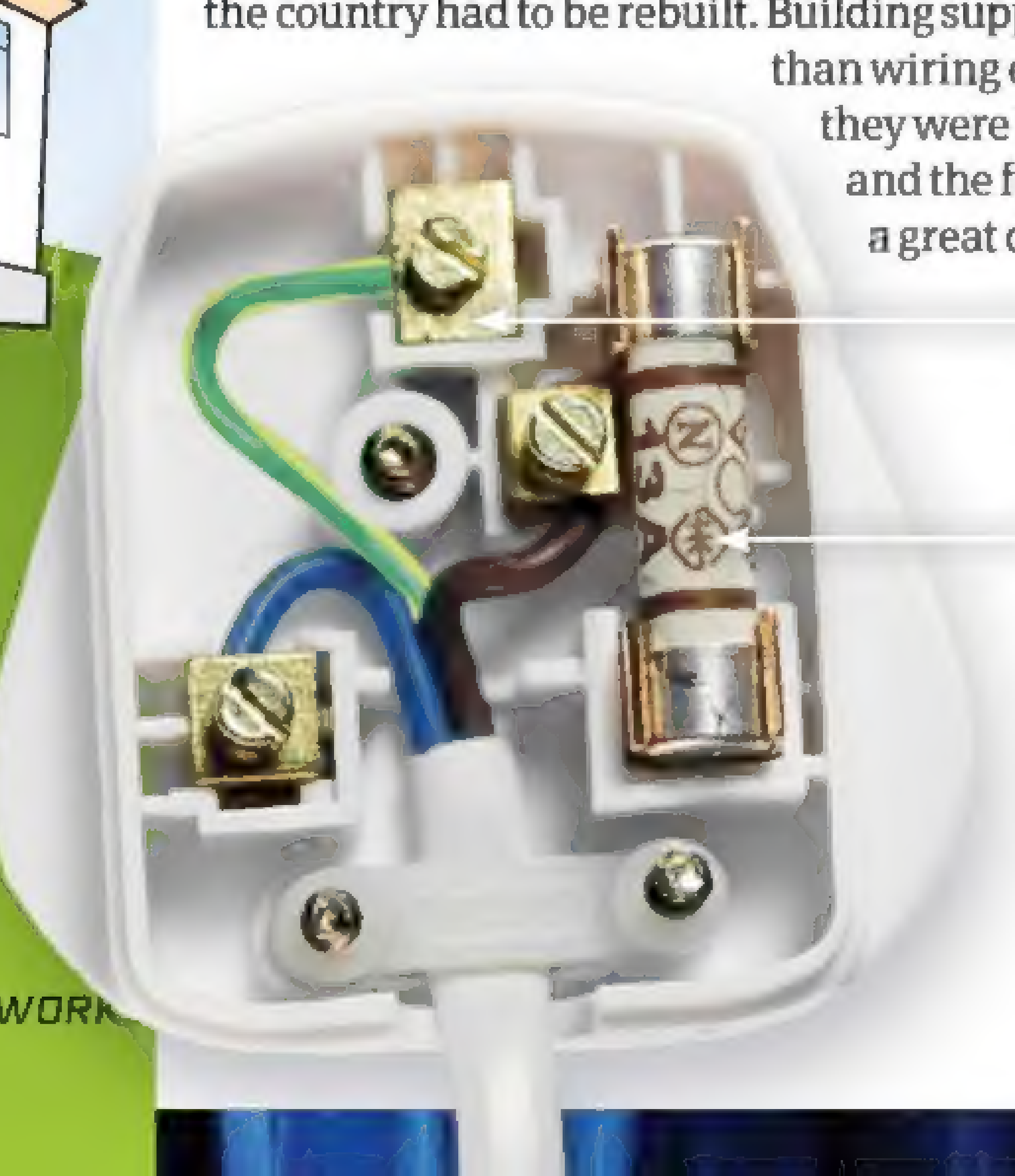
As we've seen, the word electricity is derived from the fact that current is electrons moving along a conductor that have been harnessed for energy. The difference between alternating current (AC) and direct current (DC) is related to the direction in which the electrons flow. In DC the electrons flow steadily in a single 'forward' direction. In AC electrons keep switching directions. The power supplied by electricity companies is AC because it's much easier to transport across long distances, it can easily be stepped up to a higher voltage with a transformer. It's also more efficient to send along power lines before being stepped down by another transformer at the customer's end.



Why are British plugs so big?

We owe our plugs to WWII

Visitors to and natives of the British Isles get to use one of the weirdest plugs in the world; unlike many other plugs it has a fuse built in. After being bombed heavily by the Germans during World War II, much of the country had to be rebuilt. Building supplies were short so rather than wiring each socket to a fuseboard they were linked together on one wire and the fuses put in each plug, saving a great deal of copper in the process.



1. Ground to earth
The earth wire is there to prevent electric shock and is secured by a screw terminal.

2. Fused
The fuse is designed to blow and break the circuit if the appliance gets too much current.

Inside a British plug

Why do all countries have different plugs?

"Dammit, all I wanted was a %$**@* shave!"

Even more than baggage handling and passport control, one of the biggest problems faced by the frequent traveller is the fact that every country in the world has different plugs. In the US, shortly after the AC/DC battle had been resolved (AC won) a man named Harvey Hubbell invented the two pin plug "so that electrical power in buildings may be utilised by persons having no electrical knowledge or skill" (his words). This was later developed into a three pin plug by Philip Labre in 1928 with the third pin for grounding. At the same time developments like this were occurring all around the world with absolutely no global-standardisation. There was some effort made by the International Electrotechnical Commission shortly before the Second World War occurred and spoilt it all!

Two pin or three pin? It depends where you are!

"From an electron's perspective, it's like trying to negotiate a crowded dancefloor without spilling your drink"

How do superconductors work so efficiently?

Superconductors may seem like perfectly ordinary materials, but turn down the thermostat and their superpowers are revealed…

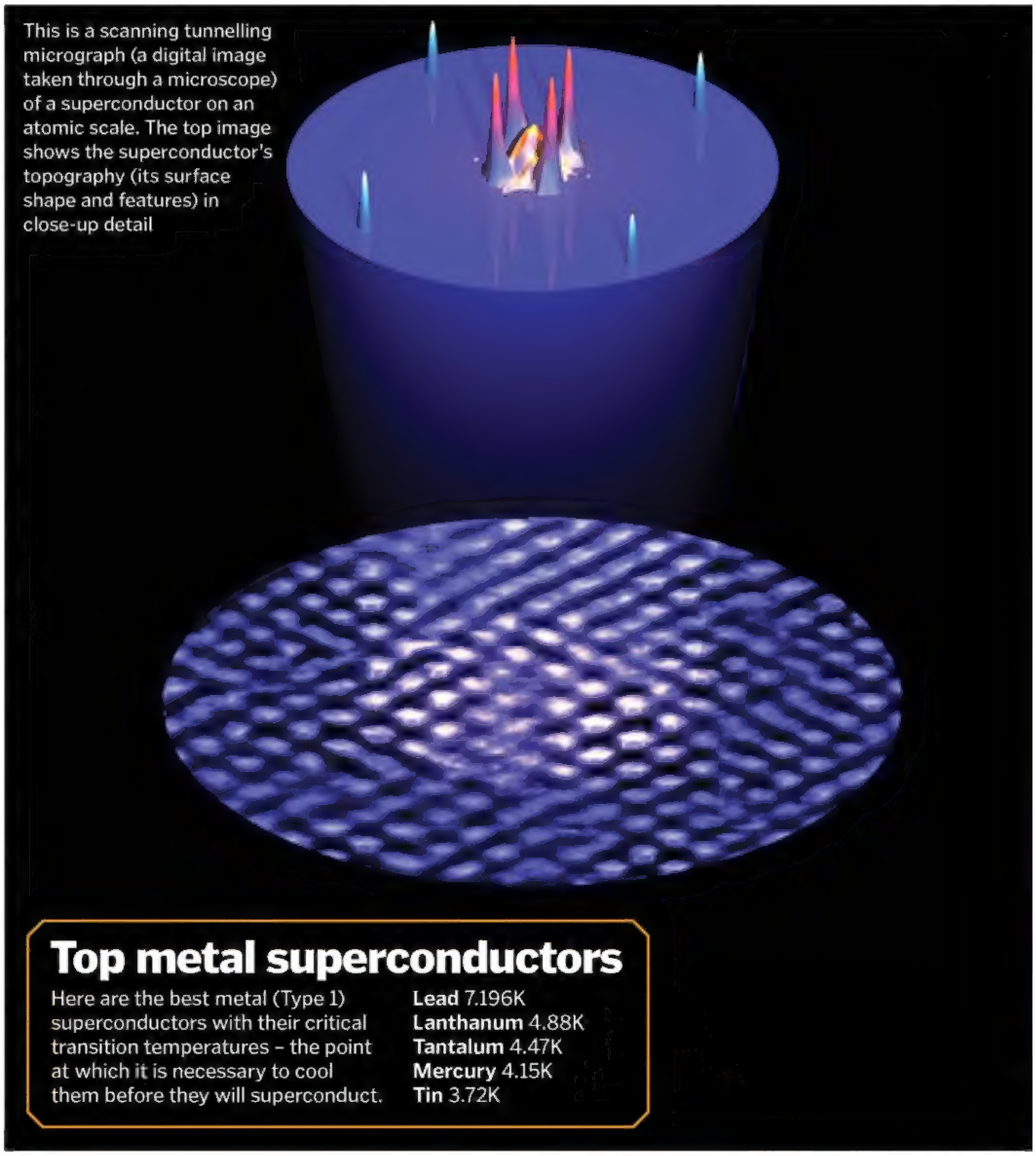
Superconductors are metals (such as lead) or oxides which conduct electricity with no resistance. There's just one catch – to display their superpowers, they need to be kept at a frosty -260 or so degrees Celsius (-436 degrees Fahrenheit).

Peer inside a chunk of lead and you'll see row upon row of neatly packed ions, bathed in a swarm of electrons. These loose electrons are what conduct electricity – set them into motion and you have an electrical current. At room temperature, the lead ions vibrate away frenetically. From an electron's perspective, it's like trying to negotiate a crowded dancefloor without spilling your drink. Constant collisions between electrons and ions convert electrical energy into heat; this is resistance.

Turn the temperature down a few hundred notches though and the ion vibrations subside, creating a stable lattice. Now, as electrons flow through, a new effect comes into play: distortions in the lattice force them into pairs.

These unlikely unions trigger a weird quantum physics quirk: electron pairs throughout the material coalesce into a perfectly synchronised cloud, moving a bit like a school of fish. This means that the swarm of electrons can move through the lattice with no collisions, resulting in no resistance.

Thanks to this astounding property, a huge current can be run through a superconductor without it overheating. This means they can create incomparably powerful electromagnets. These are currently used in MRI scanners, supercomputers, particle accelerators (like the LHC) and levitating maglev trains.



This is a scanning tunnelling micrograph (a digital image taken through a microscope) of a superconductor on an atomic scale. The top image shows the superconductor's topography (its surface shape and features) in close-up detail

Top metal superconductors

Here are the best metal (Type 1) superconductors with their critical transition temperatures – the point at which it is necessary to cool them before they will superconduct.

Lead 7.196K
Lanthanum 4.88K
Tantalum 4.47K
Mercury 4.15K
Tin 3.72K

Superconductor evolution

How It Works takes a journey through the last century to see just how far superconductors have come…

1911

Absolute zero

Dutch physicist Kamerlingh Onnes (right) and a student create temperatures just below absolute zero and uncover that mercury is a good superconductor.

1933

Levitation

Meissner and Ochsenfeld discover the Meissner effect: the uncanny ability of superconductors to repel magnetic fields and cause magnets to levitate.

STRANGE BUT TRUE
KERMIT'S ON THE UP IN HOLLAND

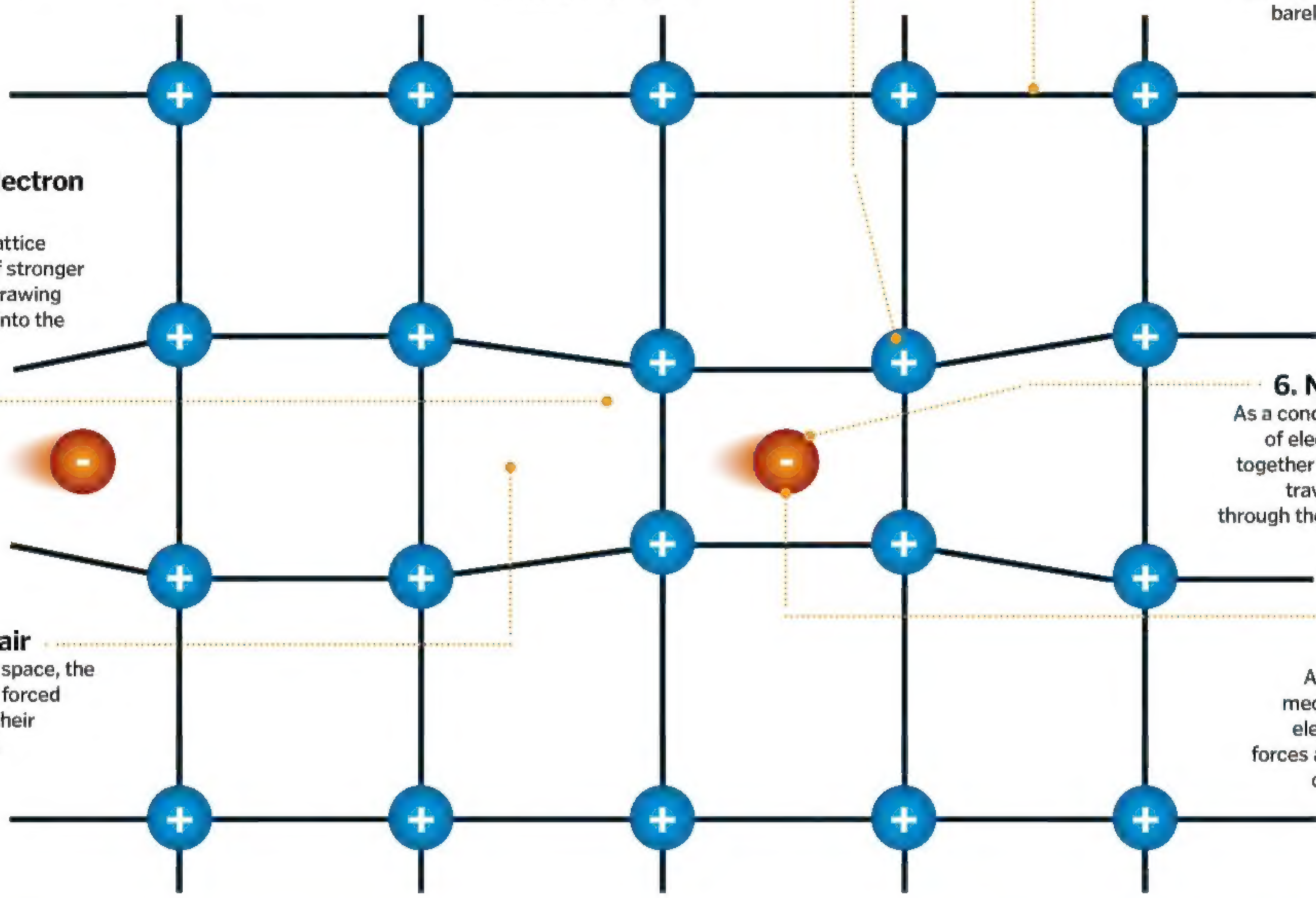
Floating frogs

Superconducting electromagnets keep massive maglev trains off the ground, but they can in fact lift any material. In a slightly unconventional experiment, scientists in the Netherlands levitated a frog. Afterward, it hopped away unscathed.

DID YOU KNOW? *Just four people have won two Nobel prizes – superconductivity theorist John Bardeen is one of them*

Superconductor in action

Find out how superconductors make life a whole lot easier for passing electrons



1. Frozen lattice
At temperatures approaching absolute zero, the superconductor's ions barely vibrate, forming a stable lattice.

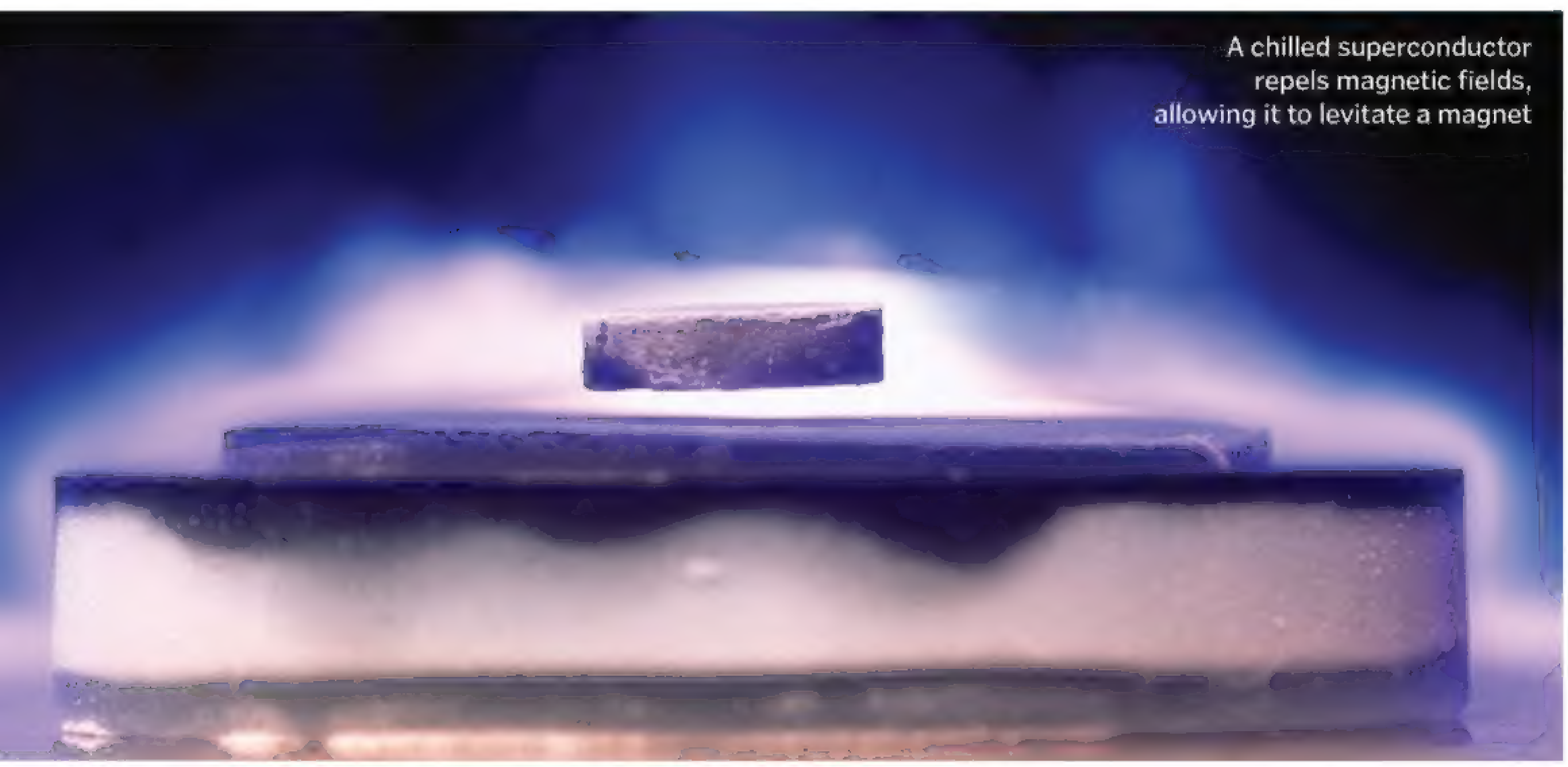
2. Bending the lattice
As a negatively charged electron makes its way through, the positively charged ions are attracted into its path.

3. Another electron is drawn in
This bend in the lattice creates an area of stronger positive charge, drawing another electron into the same space.

4. Electron pair
Trapped in a tight space, the two electrons are forced together despite their negative charges.

5. Electron pairs unite
A quirk of quantum mechanics allows the electron pairs to join forces as a Bose-Einstein condensate (BEC).

6. No resistance
As a condensate, the cloud of electron pairs moves together in perfect unison, travelling unhindered through the superconductor.



A chilled superconductor repels magnetic fields, allowing it to levitate a magnet

The potential of superconductivity

Despite their impressive abilities, most current superconductor technologies remain chained to hi-tech science laboratories, burdened by bulky, energy-greedy and very expensive cooling systems in order to function.

Scientists have, however, set their sights on creating a superconductor that works at room temperature, which could bring cutting-edge technologies into all of our day-to-day lives. Inexpensive, portable MRI scanners could drastically improve healthcare, while superfast maglev trains would zip up and down the country, considerably reducing travel times.

Replacing our inefficient electrical grids with superconducting cables would slash our electricity bills. It could also give renewable energies – such as wind farms – which are often located great distances from our cities a much deserved boost. Elsewhere, superconductor-enabled electronics could see smaller, faster computers hit the high street.

While physicists have created superconducting materials operational at temperatures up to a 'balmy' -138 degrees Celsius (-211 degrees Fahrenheit), the mechanism behind these is not yet understood. Many still believe that the Holy Grail of room temperature superconductors is achievable – it's just a matter of time and patience before we discover it.

1935
Brothers London
Fritz and Heinz London reconcile superconductor theory to show that zero resistance and the Meissner effect stem from the same phenomenon.

1957
BCS
Bardeen, Cooper and Schrieffer propose the BCS theory of superconductivity, explaining electron pairing. It earns them a Nobel prize.

1986
Hot stuff
Bednorz and Müller discover the first 'high-temperature' superconductor, which works its magic up to -243°C (-405°F).

2009
Hotter stuff
Today's superconductivity temperature record is set by mercury barium calcium copper oxide, which acts as a superconductor up to a 'blistering' -138°C (-211°F).

AMAZING ENGINEERING!

ELECTRIC POWER

One of the cornerstones of modern society, electricity has been ever-present in our lives for over 100 years. While its production methods may have varied, its application and necessity ensure it will be ingrained in our lives for years to come. But what's next for electricity, how is it distributed, and how important is it really in our lives?

A single power plant can power 180,000 homes

Electricity travels over 100,000 miles per second

UK usage 2010: 44,000MW

Powerlines can carry 400,000 volts

DID YOU KNOW?

Why aren't plugs universal?

In the 1960s, when countries were beginning to set up their own power grids, each independently developed their own plugs to distribute power to homes and businesses. Today, each is heavily invested in their own design, so switching to a universal one would be impossible.

Electricity generation STEP-BY-STEP

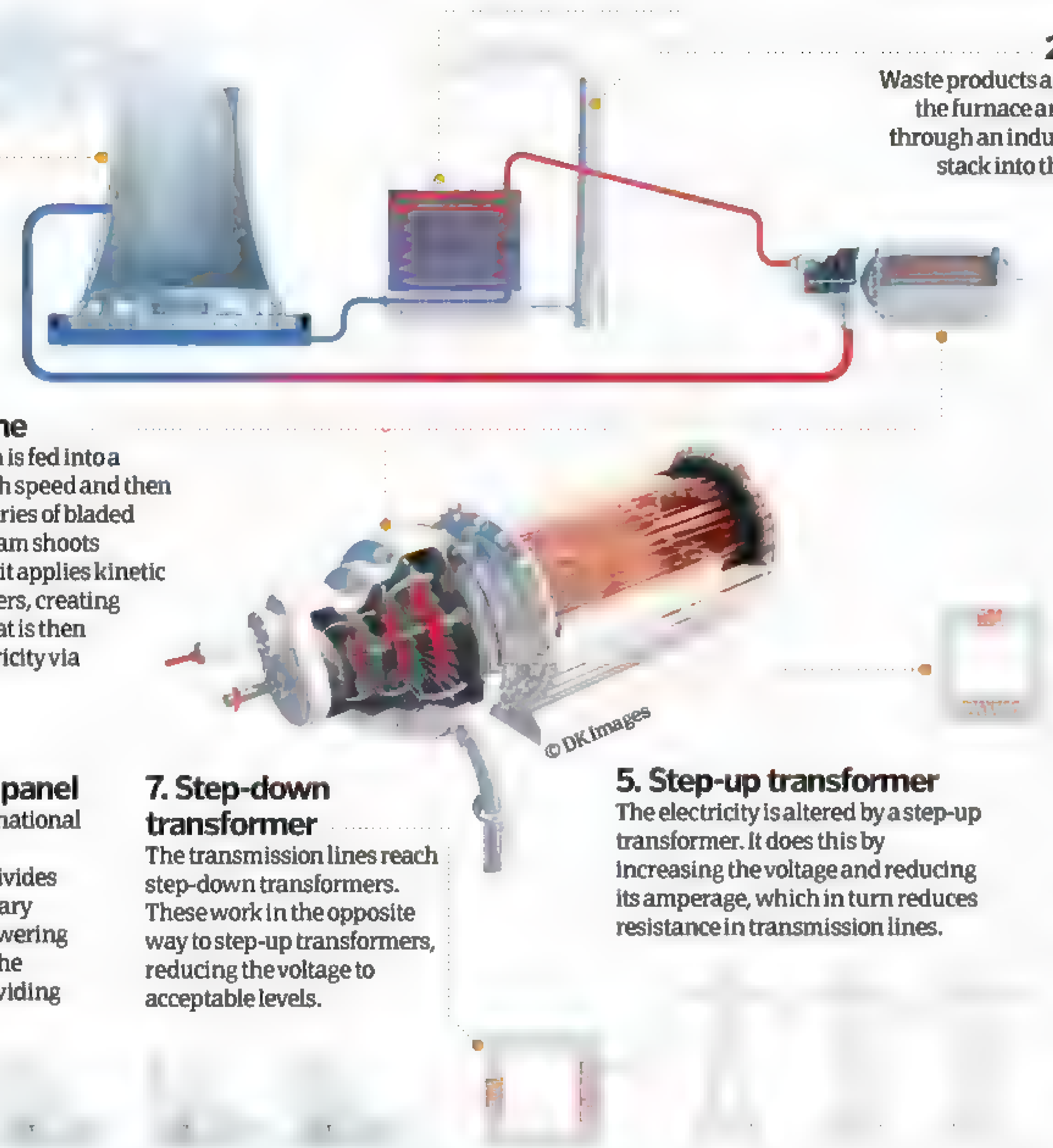
From coal-powered plants to the personal PC, How It Works explains the machinery and processes that deliver electricity to your home

1. Boiler
The process starts with the burning of fossil fuels, such as coal, in a furnace in order to fire a boiler. The boiler, when supplied with water, generates steam for utilisation in a steam turbine.

2. Chimney
Waste products and smoke from the furnace are then emitted through an industrial chimney stack into the atmosphere.

3. Steam turbine
High pressure steam is fed into a steam turbine at high speed and then compounded by a series of bladed impellers. As the steam shoots through the turbine it applies kinetic energy to the impellers, creating rotational energy that is then converted into electricity via a generator.

4. Cooling tower
The steam is filtered from the turbine to a large cooling tower, where it cools until it condenses into water.



© DK Images

5. Step-up transformer
The electricity is altered by a step-up transformer. It does this by increasing the voltage and reducing its amperage, which in turn reduces resistance in transmission lines.

6. Pylons
The high-voltage electricity feed is then distributed over large distances by electricity pylons.

7. Step-down transformer
The transmission lines reach step-down transformers. These work in the opposite way to step-up transformers, reducing the voltage to acceptable levels.

8. Distribution panel
The end stop for the national electricity grid, the distribution panel divides the feed into subsidiary circuits for use in powering electronics around the home, as well as providing protective fuse/ circuit breakers.

Today, electrical power remains unrivalled in most of its applications. From kitchen appliances to televisions, electricity provides necessary energy throughout almost the entire world. However, the source of this electricity varies wildly from place to place, with some countries moving to greener technologies, and others remaining in the age of fossil fuels. For example, over 75 per cent of the electricity generated in France comes from nuclear power, with just five per cent from fossil fuels, but In the US almost 50 per cent of electricity comes from fossil fuels (mainly coal), with just over 20 per cent from nuclear power. But where does all this electricity actually come from? And what is really going on behind the scenes?

Electric power is distributed from power stations to your home through the power grid. In the UK this is known as the National Grid, while in the USA each state has its own power grid. Overhead lines have become such a part of our daily lives that we sometimes fail to notice them, but they're all around us and constantly supplying the electricity we need to power the world. All forms of electric power generation are fundamentally the same: some source of energy has to spin an electric generator. However, each method goes about doing this in different ways.

Electric generators convert mechanical energy into electrical energy. This is made possible by the relationship between magnetism and electricity, first noted by scientist Michael Faraday in 1831. A magnetic field will induce an electric current on an electrically conductive material, such as a wire, that passes through it. This is achieved by keeping the material or magnet stationary, and rotating the other around it on a turbine. As the magnet passes each section of wire, it induces a small electric current, and by continuing this across the entire wire, a large electric current is produced. Different electric power stations use different methods to cause this rotation, but the end result is always the production of electricity. The most common method of electric power generation is the steam turbine, found in fossil fuel power plants. By burning coal, oil or natural gas, steam is created that turns the generator to create electricity. Steam can also be ▸

Electrical definition glossary

Your guide to the language of electricity production, and how it's distributed to the home

ELECTRICITY
A form of energy associated with stationary or moving electric charges that provide power to devices that create light and heat. Electricity is the result of the accumulation or motion of electrons.

VOLTAGE
The force of an electric current as measured in volts – a unit of electrical potential, potential difference and electromotive force in the metre-kilogram-second system (International System of Units, SI).

WATTAGE
A unit of power in the International System of Units (SI) that is equal to one joule of work performed per second. Most electrical equipment is rated in watts, such as a 60-watt lightbulb.

CURRENT
The movement of any type of electric charge carriers, such as electrons, protons, ions or holes. When powering electrical devices through wire, the current is the quantity of charge passing any point per unit of time.

ALTERNATING CURRENT
A flow of electric charge that periodically reverses direction between two maximum values (the current's amplitude). In domestic electronics, low-frequency alternating currents are common.

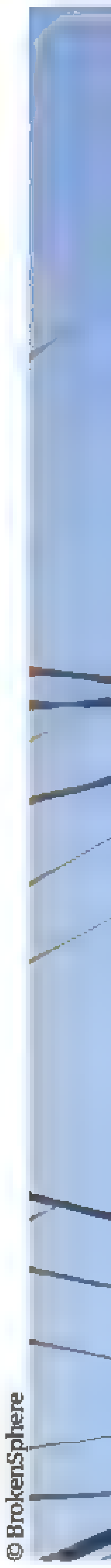
DIRECT CURRENT
The opposite of alternating current. Direct current is a flow of electric charge that does not change direction. Direct current is produced by batteries, fuel cells and rectifiers.

TRANSFORMER
A device that moves electric energy from one alternating current circuit to others, while either increasing or decreasing its voltage. Transformers are often used to step down the voltage in a domestic circuit.

"Alternating current is useful because it allows power to be sent across long distances"

produced in a nuclear power plant to produce the same effect. Alternatively, a hydroelectric dam can use water to turn a wheel, and ultimately power the rotating turbine of the electric generator.

Electricity that is sent to your home is in the form of alternating current (AC). Electricity you'd get from a battery is known as direct current (DC). Alternating current is useful because it allows power to be sent across long distances. Buildings are supplied with electricity from power stations, and they convert this alternating current into usable power. Inside the plug of an appliance are three main components that allow this to be possible. The first is the live wire, which converts the alternating current of the grid into direct current to be used by appliances. The neutral wire carries out a similar role in addition to preventing surges of electricity by having the same electric potential as the earth, which stops the power supply rising uncontrollably in the case of a lightning storm or otherwise. The ground wire is always connected to the earth and further protects against power surges and electric shocks. Inside a plug is a fuse that is designed to melt if the wires are overcome by a large increase in current, rendering the plug inactive and preventing the circuit being completed. Safety features like these have contributed to the widespread adoption of electric power as our main source of power over the past century, and it's more than likely that we'll be relying on electric power in the same manner for many more years to come.



Be careful where you fly your kites

© BrokenSphere

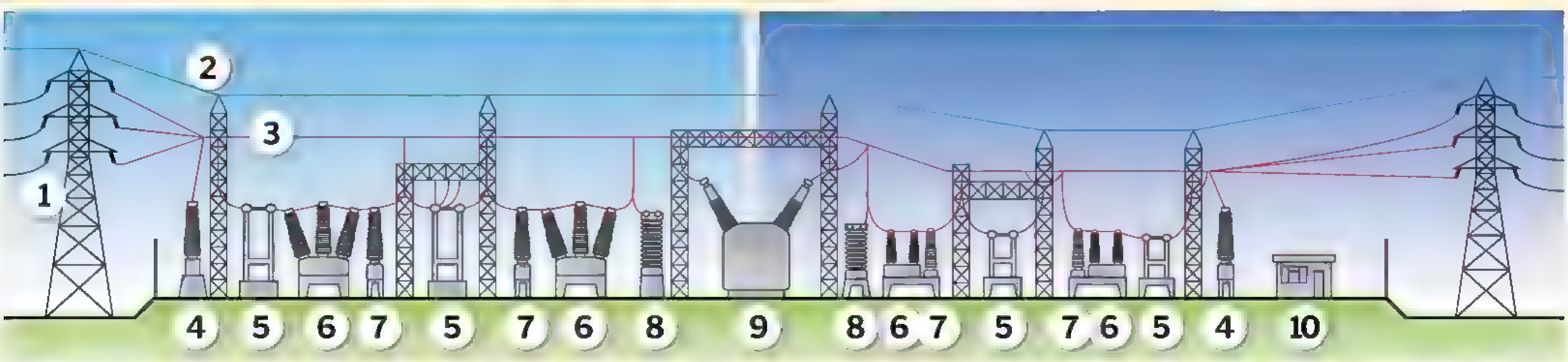
Substation breakdown

How It Works highlights and explains the key components of these complex installations

Producing electric power in a power station is all well and good, but we need to be able to convert that power into a useful source. This is the role of electric substations, which make the high-voltage electric power usable.

Transmission voltages from power stations are very large, and can potentially be dangerous if allocated incorrectly. In fact, 'plugging' your house into a transmission voltage, usually in the range of hundreds of thousands of volts, would instantly blow all the electrical appliances, sockets and wires in your house. Substations lower this voltage to a distribution voltage, normally less than 10,000 volts, and allow our homes and buildings to receive useful electric power.

Below you'll see the stages of conversion at a substation, and how an array of wires, transformers and breakers are responsible for supplying the power on which we rely.



1. Primary power lines
The power lines deliver a high or low-voltage electrical feed.

2. Secondary power lines
Whether the substation has stepped the feed's voltage up or down, the result is redistributed here.

3. Ground wire
Due to the large voltages and currents that regularly pass through the substation, it is grounded at multiple points for human safety.

4. Disconnect switch
An installation designed to disconnect the transmission lines or components to and from the system. If a transmission line develops a fault, then this can isolate it from the network.

5. Circuit breaker
Circuit breakers are used on larger substations in order to interrupt any short circuits or overload any currents that may occur on the network.

6. Current transformer
When a substation receives a current too high to measure, the current transformer reduces it, protecting the instruments and allowing an accurate reading.

7. Lightning arrester
This is a device that is used to protect the substation's insulation from the potentially damaging effects of a lightning strike.

8. Primary transformer
This is the main device that is used to step up the feed's voltage and decrease its current or step down the voltage and increase the current.

9. Control room
The control room houses access terminals needed by the electricity grid's engineers to retrieve info from the substation.

10. Enclosure
Due to the high voltages at play in a substation, any metal fencing must be grounded for public safety.

1. Nuclear
Water is heated by the process of nuclear fission in order to produce the steam required to rotate the turbine and generate electricity.

2. Coal
The largest source of energy in the USA. Coal is burned in a large furnace in order to produce steam that rotates the generator's turbine.

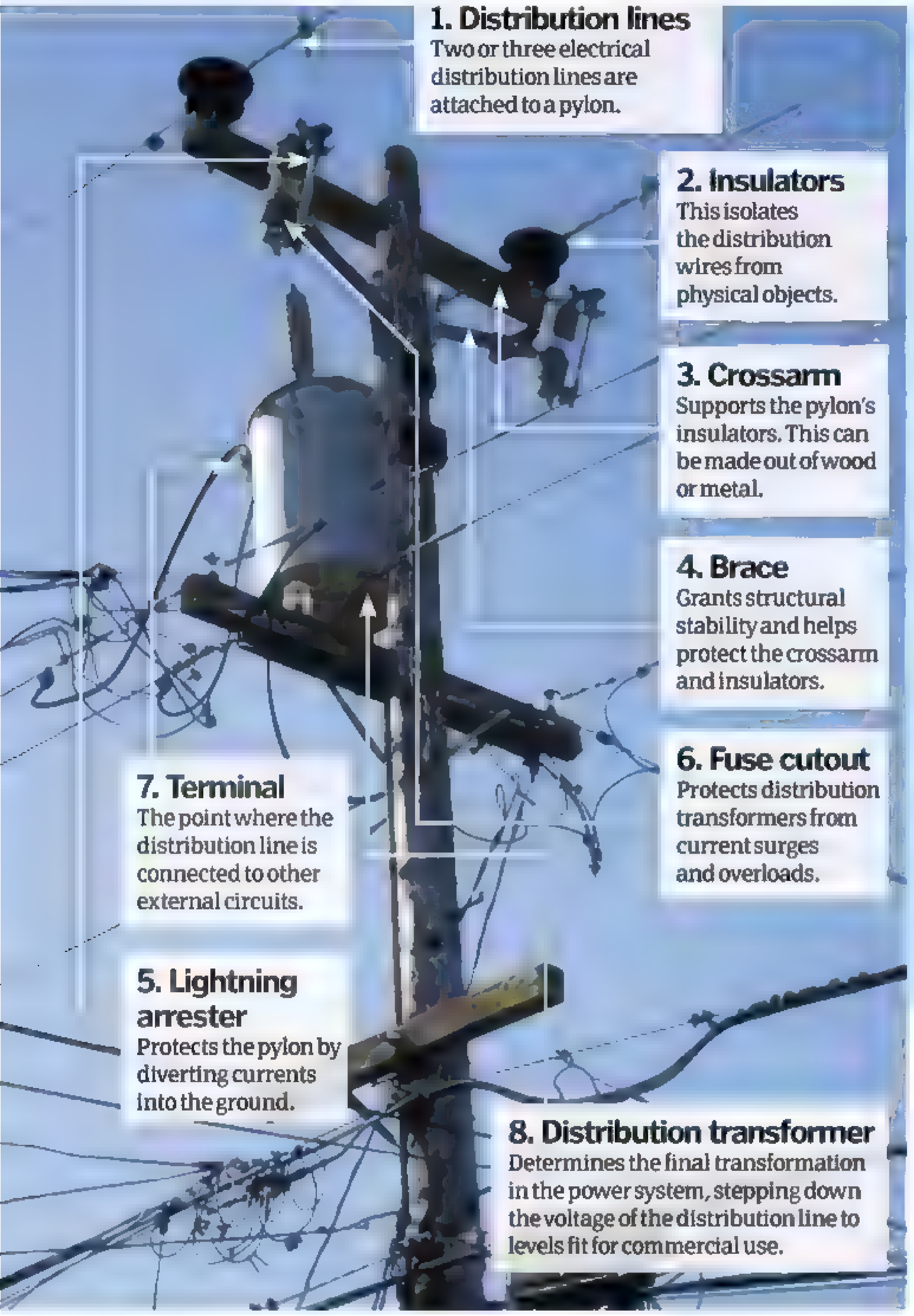
3. Hydroelectric
Water that is sourced either from a reservoir or a flowing river is diverted to rotate a wheel, which in turn rotates the turbine in order to produce electricity.

DID YOU KNOW? There are a grand total of 88,000 electricity pylons in the United Kingdom

Anatomy of electricity pylons

Getting electricity from a power station to your home is a long and convoluted process. We see electrical pylons (known as transmission towers in the United States) almost daily, but they're such a regular part of our lives that we often fail to notice them, much less appreciate the job these structures perform. Pylons work in tandem across great distances in countries around the globe to provide the daily electricity responsible for large parts of modern life, often unknown to many despite their somewhat unsightly appearance.

Pylons are large structures that are constantly carrying high-voltage electricity. They are potentially very dangerous, and thus possess a number of safety features to protect against surges in current and overloads. They can range in height from just 15 metres (49 feet) to over 300 metres (980 feet), depending on their location and need. Check out our diagram to see just how these fascinating structures work.



1. Distribution lines
Two or three electrical distribution lines are attached to a pylon.

2. Insulators
This isolates the distribution wires from physical objects.

3. Crossarm
Supports the pylon's insulators. This can be made out of wood or metal.

4. Brace
Grants structural stability and helps protect the crossarm and insulators.

5. Lightning arrester
Protects the pylon by diverting currents into the ground.

6. Fuse cutout
Protects distribution transformers from current surges and overloads.

7. Terminal
The point where the distribution line is connected to other external circuits.

8. Distribution transformer
Determines the final transformation in the power system, stepping down the voltage of the distribution line to levels fit for commercial use.

MEGA STATS

Electricity is [illegible] business, and even [illegible] numbers. Here [illegible] a few stats that [illegible] just blow your fuse...

362,000,000,000 Kilowatt hours
The total amount of electrical energy produced in the UK from 2009 to 2010, of which 345 Bkwh were consumed. [illegible] generation comes from 80 per cent thermal sources, [illegible] per cent by nuclear plants, [illegible] by renewables and one per cent by [illegible] electricity installations.

47,000 Short tons
The quantity of coal the UK burned in electricity generation in 2010. This figure was significantly lower than 2006 – the highest point of a ten-year scale – where [illegible] short tons of coal were burned.

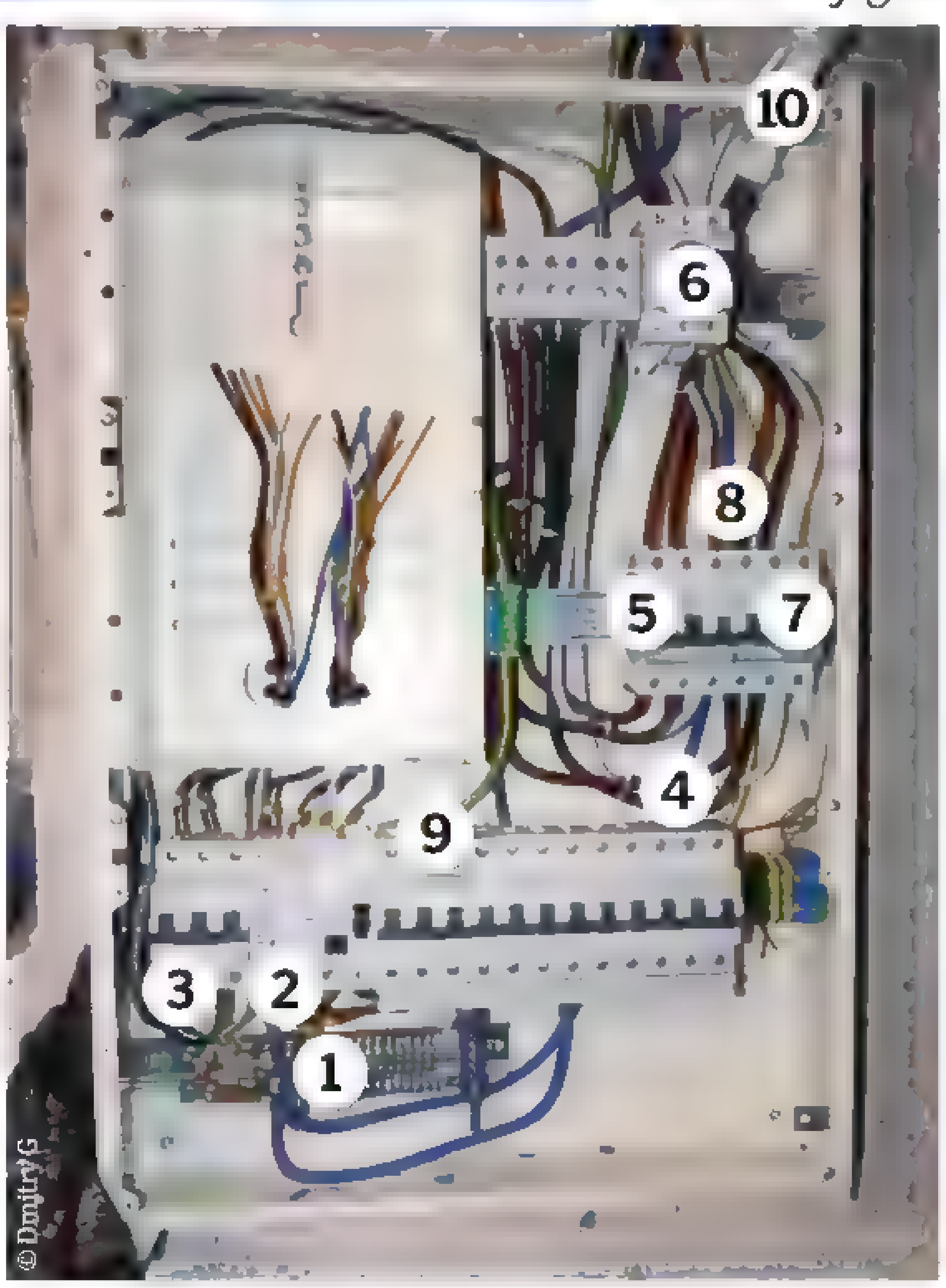
86 GIGAWATTS (GW)
[illegible] electricity generation capacity for the [illegible] electricity sector. This is [illegible] main distributors – EDF Energy, E.ON, RWE npower and Scottish and Southern Energy – over the national grid [illegible]

9,500 MEGAWATTS
The total combined electrical energy capacity of Britain's nine nuclear power plants. Eight of these plants are operated by EDF Energy, and utilise advanced, gas-cooled and pressurised-water reactors. All of the gas-cooled reactors will be in service until 2023.

4 REACTORS
The proposed number of new pressurised reactors by electricity supplier EDF Energy to meet increasing energy demands over the next two decades. The new nuclear power plants would add 6,400 megawatts of generated electricity for consumption.

Distribution panels explained

This panel forms the junction between your home's electricity circuits and the national electricity grid



1. Ground connection/ ground wire
A metal conductor is attached to the ground wire in order to protect the panel in the event of a short circuit.

2. Terminal
This is part of the ground/neutral bus bar to which the unit's ground wire attaches.

3. Bus bar
This component receives the current from the neutral grounded wires of all circuits, and re-routes them to the neutral service wire and ground connection.

4. Neutral wire
A wire with no electric charge, the neutral wire allows currents to return to the distribution panel and the electricity grid.

5. Single/double circuit breakers
Two protection devices that in the event of an electrical surge or overload, cuts off the feed of both the 120-volt and 240-volt circuits.

6. Main breaker
The main breaking unit of the entire panel, this can cease the supply of electricity to all the hot bus bars.

7. Hot bus bars
A conductive part of the panel into which the breakers for each circuit are plugged.

8. 120-volt circuit
The 120-volt circuit is formed from one live wire, one neutral wire and one ground wire. It feeds electricity to small appliances and lightbulbs.

9. 240-volt circuit
Consisting of twice the amount of wires than the 120-volt circuit, the 240-volt circuit feeds electricity to large appliances such as televisions.

10. Main power supply
The live distribution wire conducting the electric current into the panel enters through here.

"Even a single large turbine can generate an enormous amount of power"

Head to Head
DAMS

BIGGEST

1. The Three Gorges Dam
Location: Yangtze River, China
Size: It's 2,335m (7,660ft) long, 101m (331ft) wide and 115m (377ft) at its thickest point. It took 15 years, approximately £25 billion and nearly 14 million tons of cement and materials to construct it.
Facts: 34 turbines weighing in at a 6,000t each generate 22,500 megawatts for an annual output of 60.7 terawatt-hours per year in 2009. It is by far the world's largest electricity-generating plant of any kind.

TALLEST

2. Nurek Dam
Location: Vakhsh River, Tajikistan
Size: The Nurek is an earthfill dam finished in 1980 when the Soviet Union had control of Tajikistan. At 300m (980ft) it is the world's tallest dam, though the Rogun Dam has a taller proposed height for when it's eventually completed.
Facts: A comparatively modest nine hydroelectric turbines have a total power output of three gigawatts, but amazingly, since 1994 this has been enough to supply 98 per cent of the nation's total electricity needs.

MOST FAMOUS

3. Verzasca Dam
Location: Lago di Vogorno, Switzerland
Size: Not the largest nor the tallest dam at 220m (722ft) high.
Facts: The site of the scene where Bond dove off into the Verzasca River below in *GoldenEye*, it's one of the most famous dams worldwide.

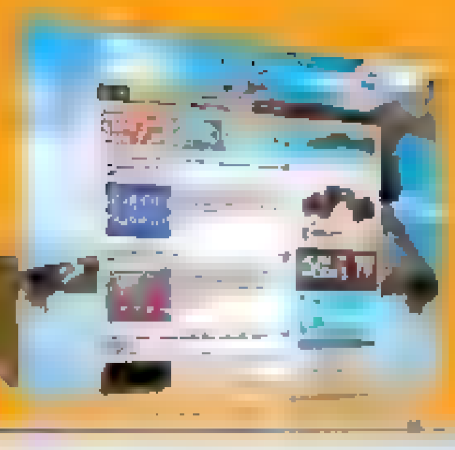
Hydroelectric power

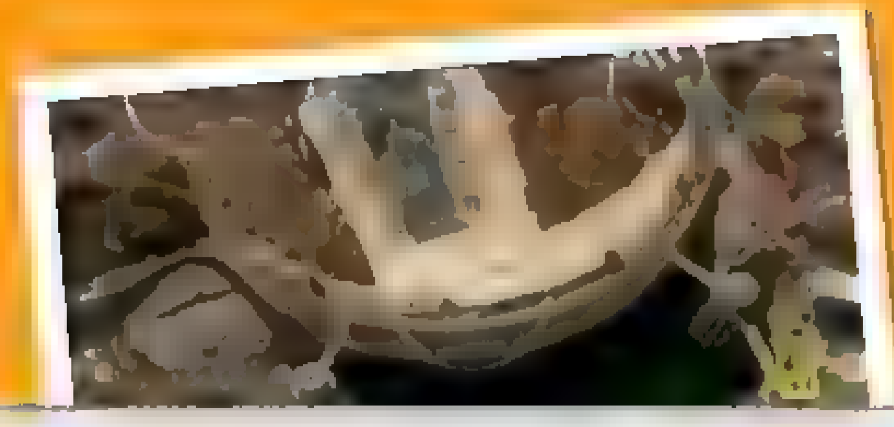
Using nature's resources to their full potential…

Water has been used to power man-made mechanisms for hundreds of years, mostly in food production in the form of a mill wheel to grind corn. But using the kinetic energy of water probably became a reality earlier than you thought. In 1878, inventor Lord Armstrong lit his home in Northumberland using only the power of a nearby waterfall. It's not until the latter half of the 20th Century that we began to take advantage of the massive potential of hydroelectric power.

Intriguingly, both the environmentally unfriendly coal-power plants and clean, green hydro-power use almost exactly the same technology to generate power. Central to a coal-fired plant is a turbine: coal is burned to produce heat energy, which is used to boil water into steam that then drives a turbine. Hydroelectric power removes the coal and steam elements and instead, flowing water turns the blades of each installed turbine.

By damming a river next to a drop in elevation and releasing a controlled flow (and creating a large body of water behind the dam called a reservoir), you can effectively harness the Earth's gravity as an energy source. It's based on the principles discovered by physicist Michael Faraday: when a magnet moves past a conductor, it creates electricity. When the water flowing





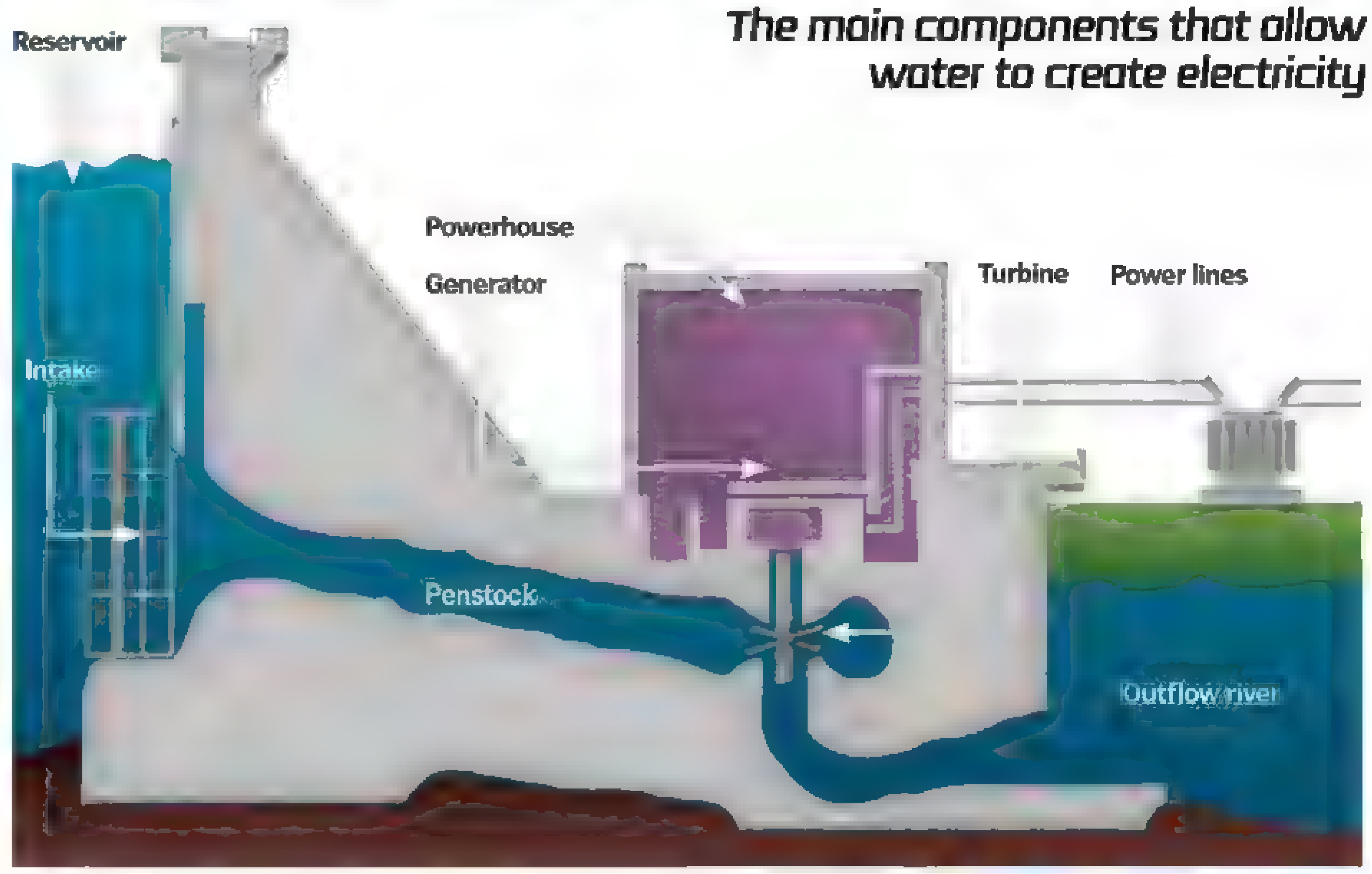
The huge generators inside the Hoover Dam

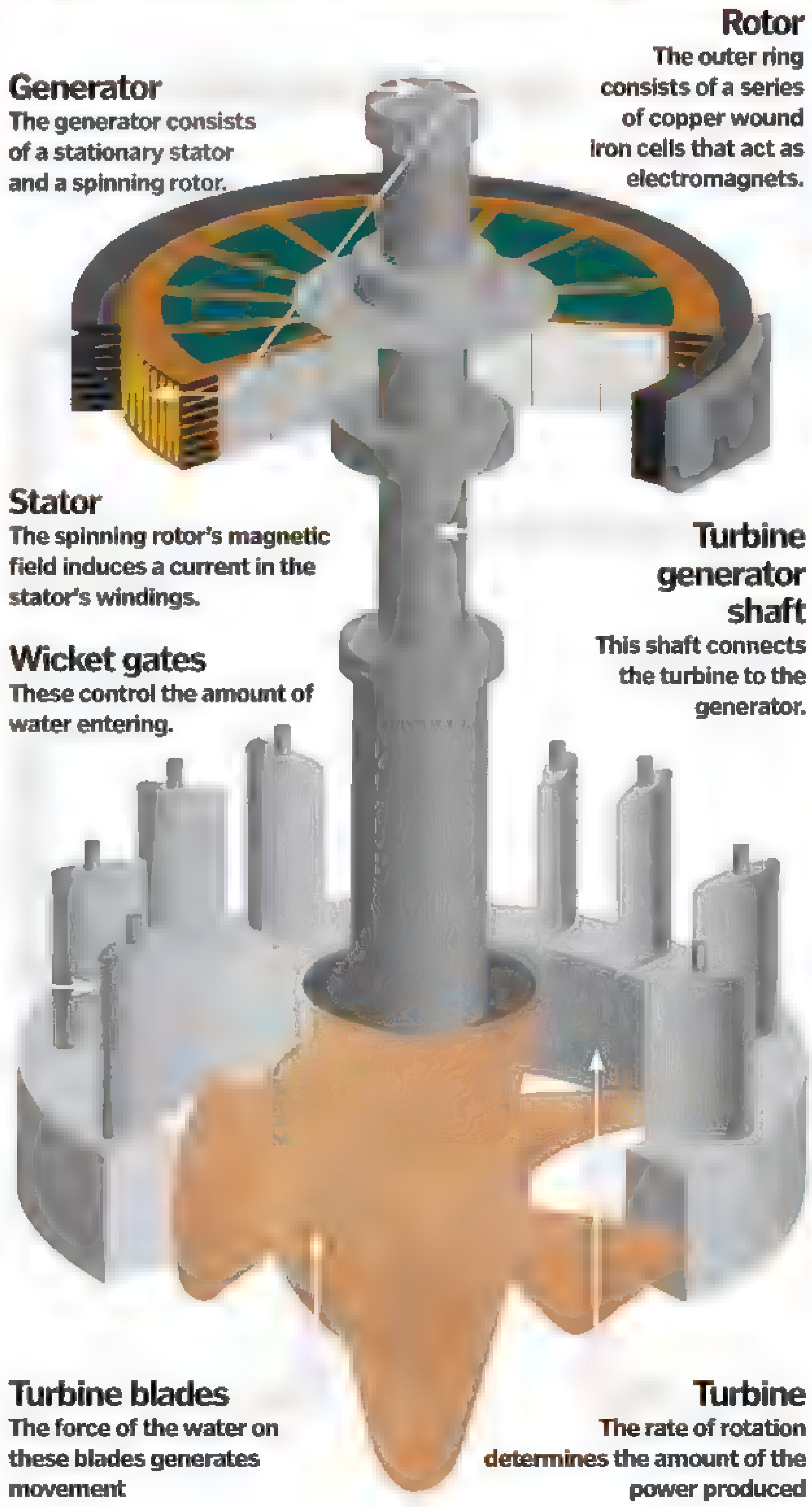
through a hydroelectric turbine turns the blades it rotates a shaft attached to a large disk called a rotor at the opposite end. The rotor is made up of loops of wire with current circulating through them, wound around stacks of magnetic steel. When active, the turbine propeller turns the rotor past the conductors located in the static part of the turbine, known as the stator.

Modern technology in even a single large turbine (which can weigh thousands of tons) can generate an enormous amount of power, but the cost-effectiveness of building the dam as well as the environmental and economic impact of flooding the area behind it can prohibit such ventures.

Inside the dam

The main components that allow water to create electricity





TYPES OF... DAM

1 Saddle
Often constructed as an auxiliary to the main dam, at a dip (or saddle) where water would otherwise escape.

2 Diversionary
Often a controversial construction, these are created with the pure intention of diverting a river from its course.

3 Dry
These are designed to control flooding, allowing the river to flow freely except in times of intense rainfall where flooding is more likely.

4 Overflow
These are made with the intention of having the river flow over the top of the dam, most often to measure flow and for drinking water.

5 Check
Check dams are used to slow the rate of flow of the river with the expressed intention of controlling soil erosion.

For more information about the Hoover Dam visit **www.pbs.org/wgbh/americanexperience/hoover/** where you can watch a video on how the dam was built and the mammoth task that was involved.

"Turbines are the next natural technological evolution of the water wheel"

HOW WATER TURBINES WORK

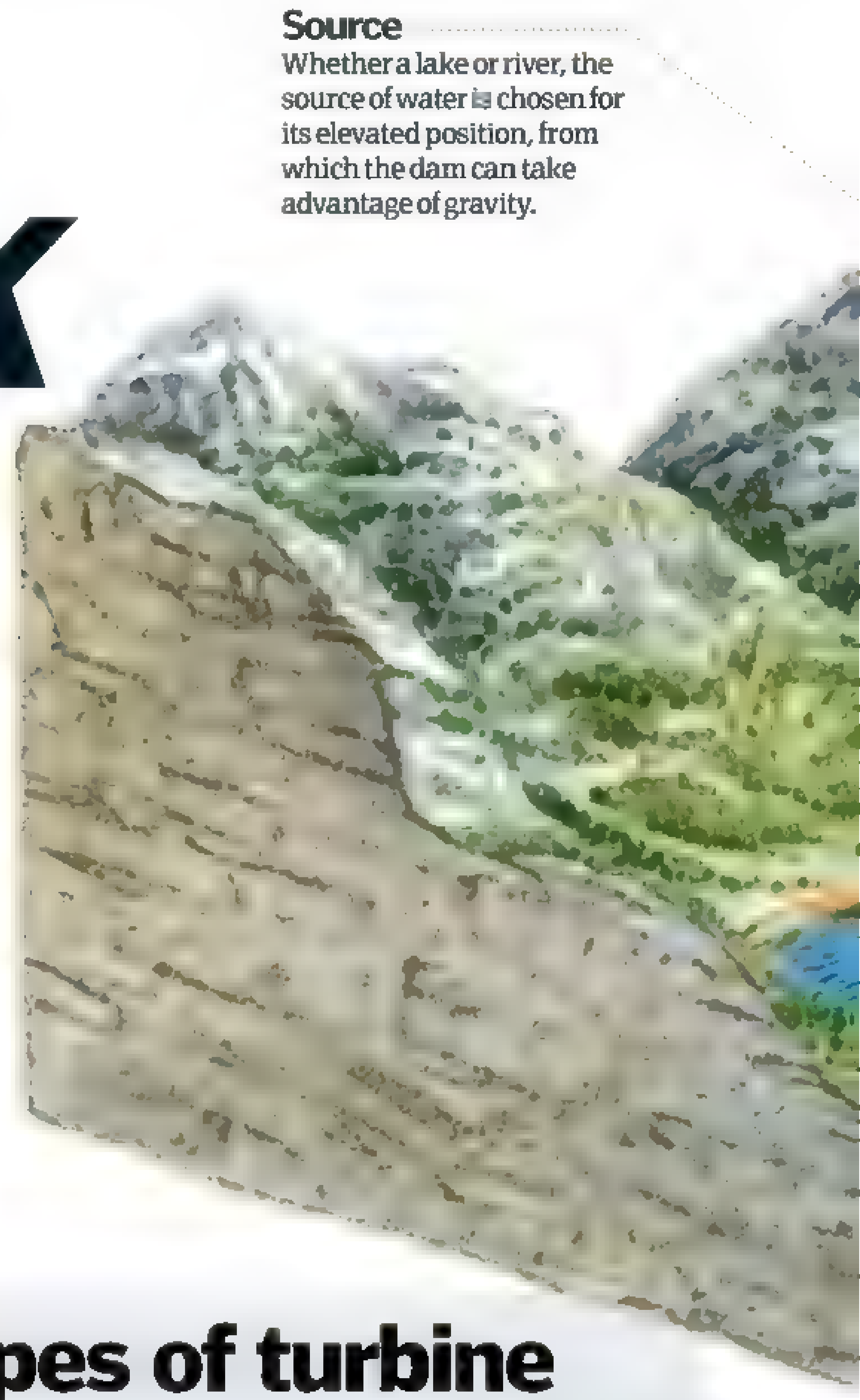
The simple technology that harnesses the immense natural power of water

Water wheels have been around for several thousand years, the concept of using water to power basic machinery like mill wheels – essentially harnessing the Earth's gravity – being well within the grasp of ancient engineers. Turbines are the next natural technological evolution of the water wheel and, although the Romans sometimes used a form of turbine for their water wheels and agricultural uses, it wasn't until the Industrial Revolution in around 1750-1850 that the first modern turbines emerged.

Turbines are essentially propellers in reverse, both of which work in direct accordance to Isaac Newton's third law – namely, for every action there has to be an equal and opposite reaction. In propellers, that means energy is put into a spindle of asymmetrical blades that puts pressure on the air or water, which pushes back to propel the vehicle.

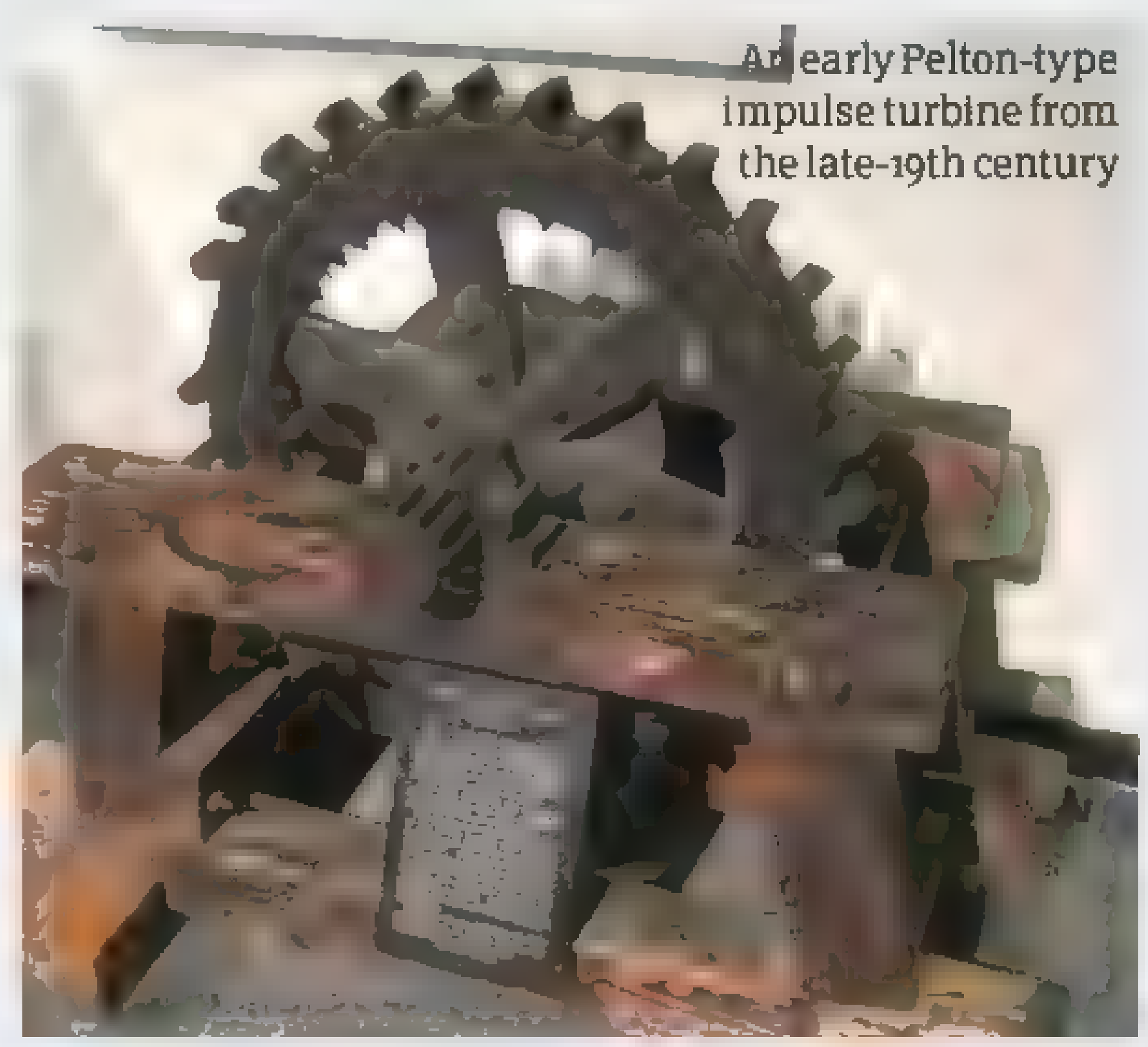
Turbines are usually fixed in place, so when a fluid flows through it there is a drop in pressure at the back edge of each blade that causes the turbine to turn. The principle is the same for air or water and the faster the medium is moving, the greater the pressure drop, and the faster the turbine spins.

It's a much more efficient method than water wheels that yields greater hydraulic head – the amount of force the water can generate – with smaller apparatus. Turbines directly drove the huge factories of the 19th century, but since the dawn of electricity, they're used to generate power that can be stored or passed on to the national electrical grid for a clean and renewable source of power.

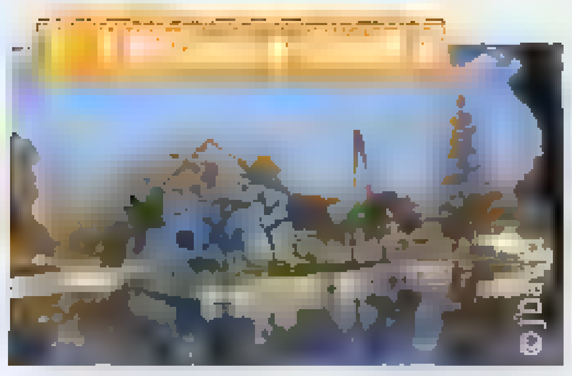


Types of turbine

There are two main types of turbine: impulse and reaction. Essentially these names describe the different blade mechanism used. In impulse turbines, where water jets onto the blades, the pressure drop – where the energy transfer occurs – takes place in the convergent guide vanes that direct the fluid onto the rotor blades. The opposite happens in a reaction turbine, where the rotor blades have convergent passages and the pressure drop happens here. Impulse turbines are usually unsuitable for low-head sites because they have low specific speeds, but they're easier to maintain. Reaction turbines, on the other hand, can rotate faster given the same head and flow conditions, but generally require a greater level of maintenance.



An early Pelton-type impulse turbine from the late-19th century



Trzebiatów Hydro Station
Micro-hydroelectric powerplants, like the 155kW Trzebiatów Hydro Station in Poland, can be a greener option than larger dams.

Gordon Dam
The Gordon Dam in Tasmania has a 430MW capacity, making it something of a middleweight as far as hydroelectric dams go.

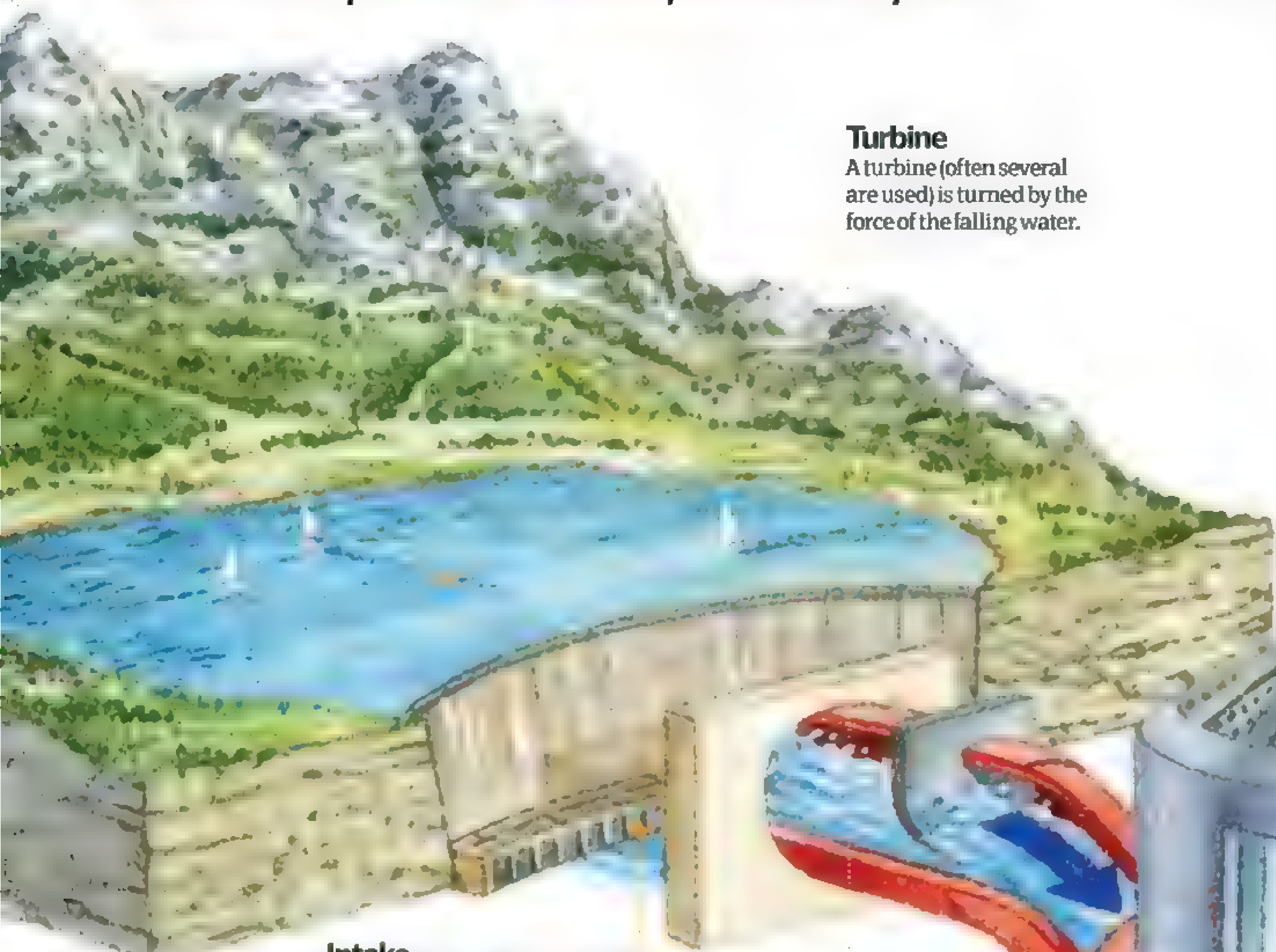
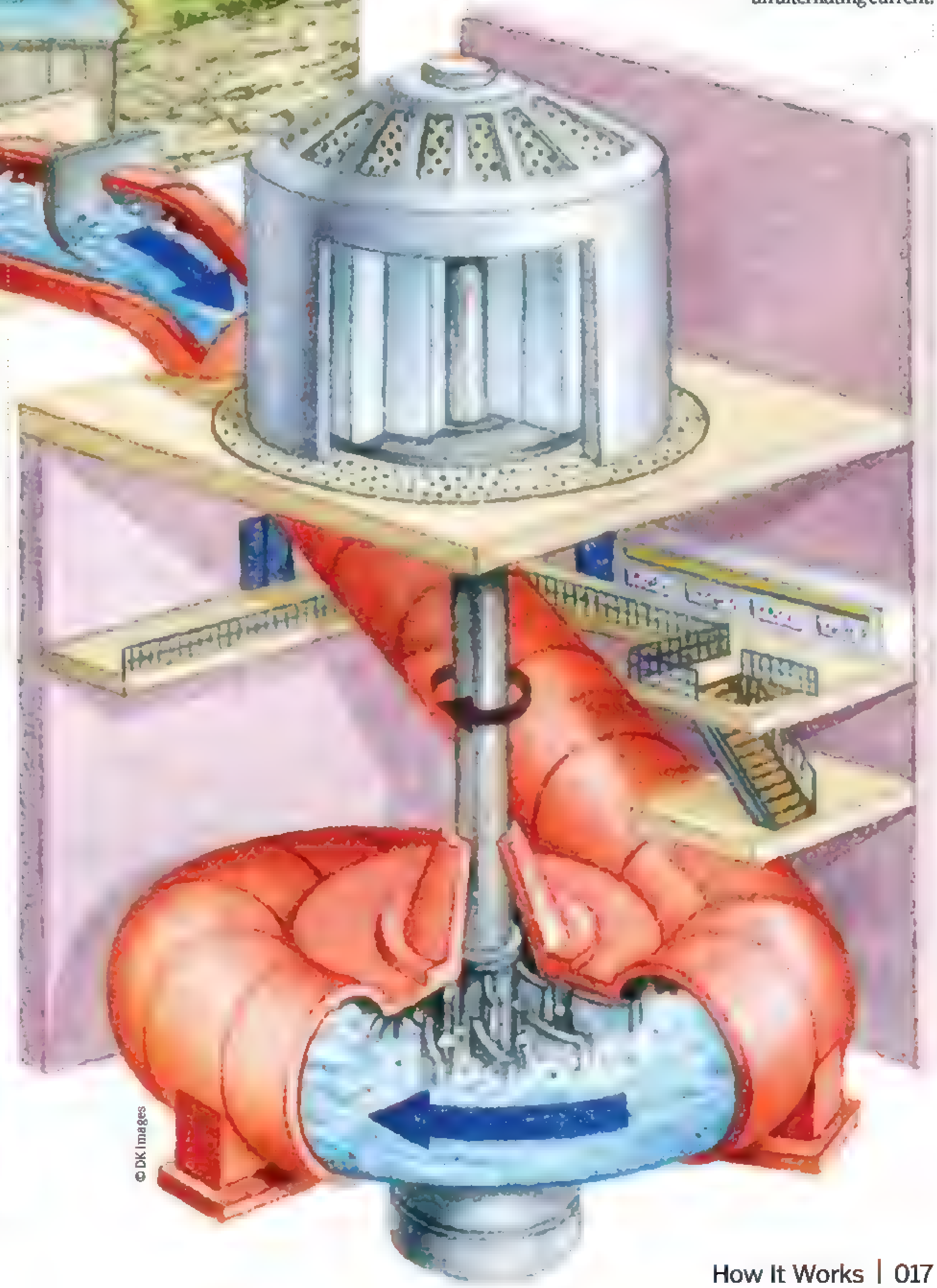
Three Gorges Dam
Easily the world's biggest hydroelectric powerplant is the Three Gorges Dam, which spans the Yangtze River in central Hubei, China. It can boast a staggering 18,200MW capacity.

DID YOU KNOW? A prototype wind turbine in Abu Dhabi also creates 1,000l (265ga) of drinking water daily via condensation

Turbines in context

A lake or river is dammed off and the natural elevation of the site is used to provide the source of the turbine's power

> "Turbines are essentially propellers in reverse, both of which work in direct accordance to Isaac Newton's third law"

How green is hydroelectricity?

As a direct source of energy, hydroelectric power by damming a moving body of water and releasing it via a turbine is environmentally friendly. There are no direct waste products and, as long as the water flows, it's an infinite source. But that doesn't mean hydroelectric dams are completely 'green'. Construction aside, a huge area of land is flooded to create the reservoir necessary to drive the turbines, which can upset local plant and animal ecosystems. While the turbine itself has no harmful emissions, the flooded area often drowns vegetation, which then decomposes anaerobically (without oxygen) underwater and produces methane, a greenhouse gas.


The Aswan High Dam protects Egyptian crops from Nile flooding, but the creation of Lake Nasser displaced 100,000 people

© Ingenieurlösungen

The Pearl River Tower

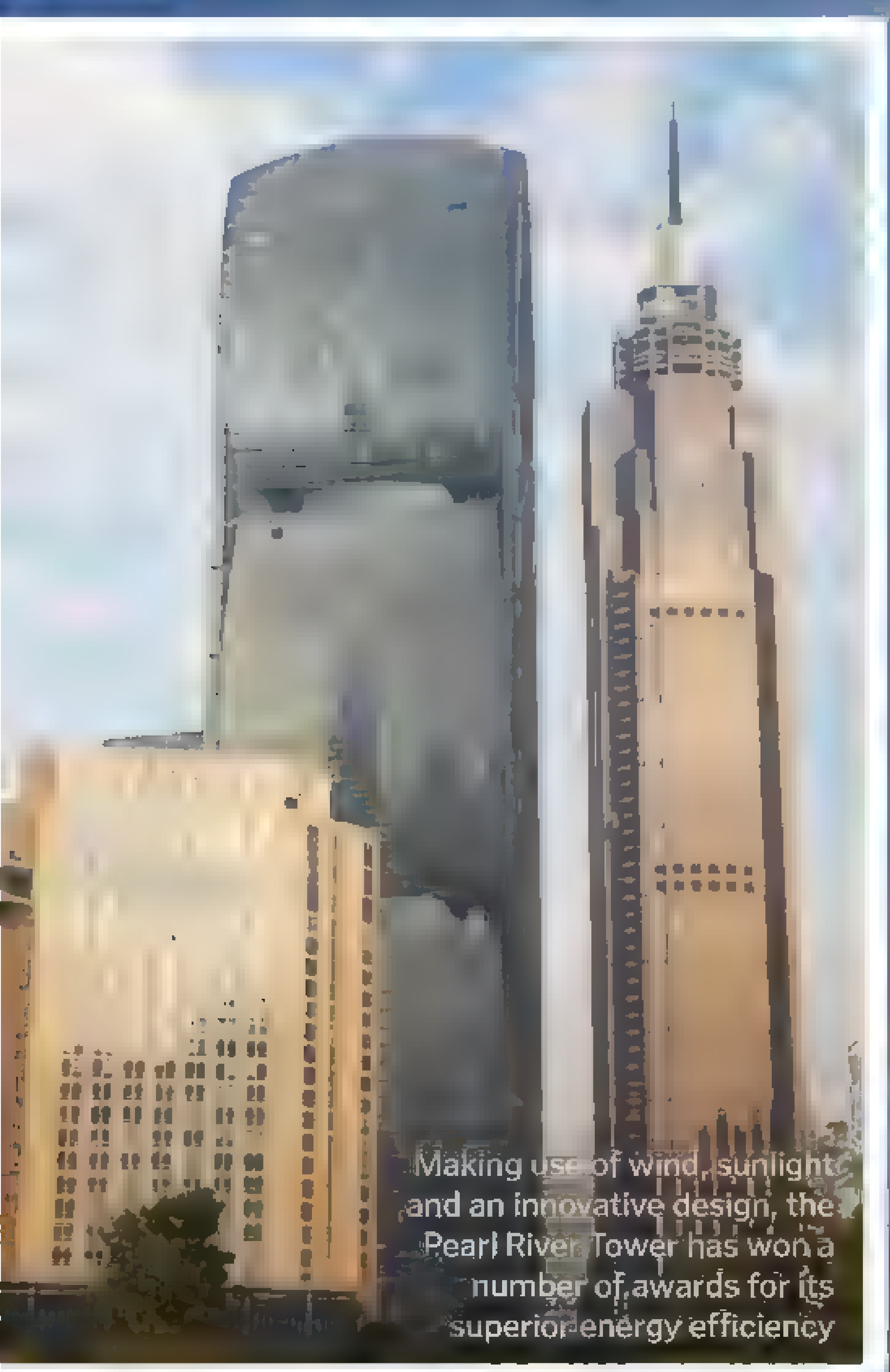
This 71-storey tower block is being touted as the greenest skyscraper on Earth, but what makes it so energy efficient?

While many buildings flaunt their green credentials by incorporating a single piece of in-your-face, eco-friendly technology into their design, the Pearl River Tower in Guangzhou City, China, goes much further, drawing together a bevy of cutting-edge systems to jump closer to an almost zero-energy building (ZEB) – the holy grail for today's architects.

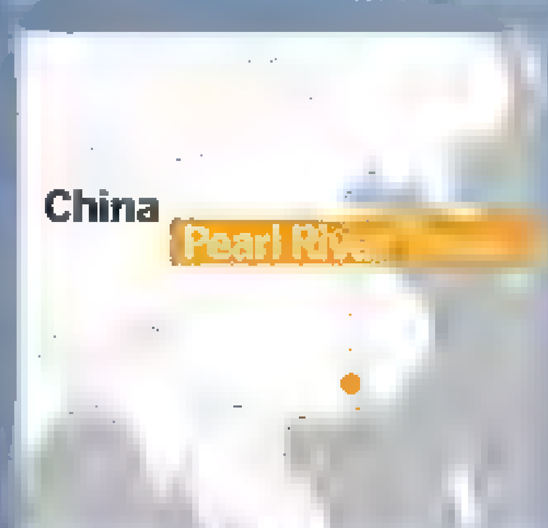
This is achieved first and foremost through its 309-metre (1,014-foot)-high sculpted faces, which redirect wind to four openings in its mechanical floors. Here, the wind is drawn through the building's body and into a series of turbines, which combined generate electricity for the offices within. In addition to driving turbines, the wind that is pulled in is also rerouted throughout the tower's ventilation system, with the air being filtered through the building's floor and ceiling spaces. This ambient cooling of the offices negates the need for energy-hungry air-conditioning units in hot weather, which saves a considerable amount of electricity.

The entire building is also fitted with an advanced, double-glazed skin. The outer layer of this can be penetrated by heat from sunlight, however the inner layer cannot, causing the rays' heat to become trapped and not enter the interior. This trapped heat therefore rises through the skin's cavity to heat exchangers where it is absorbed and stored for reuse in both energy generation and heating processes.

Last, large solar panels are installed on the building's exterior roof, which directly absorb sunlight for generating energy. This energy is used to provide power for the skyscraper's perforated metal window blinds, which automatically track the Sun and open or close to minimise heat loss or to moderate ambient office temperature. The blinds themselves are also equipped with photovoltaic cells, so even when they are closed, the Sun's energy is being efficiently harvested.



Making use of wind, sunlight and an innovative design, the Pearl River Tower has won a number of awards for its superior energy efficiency



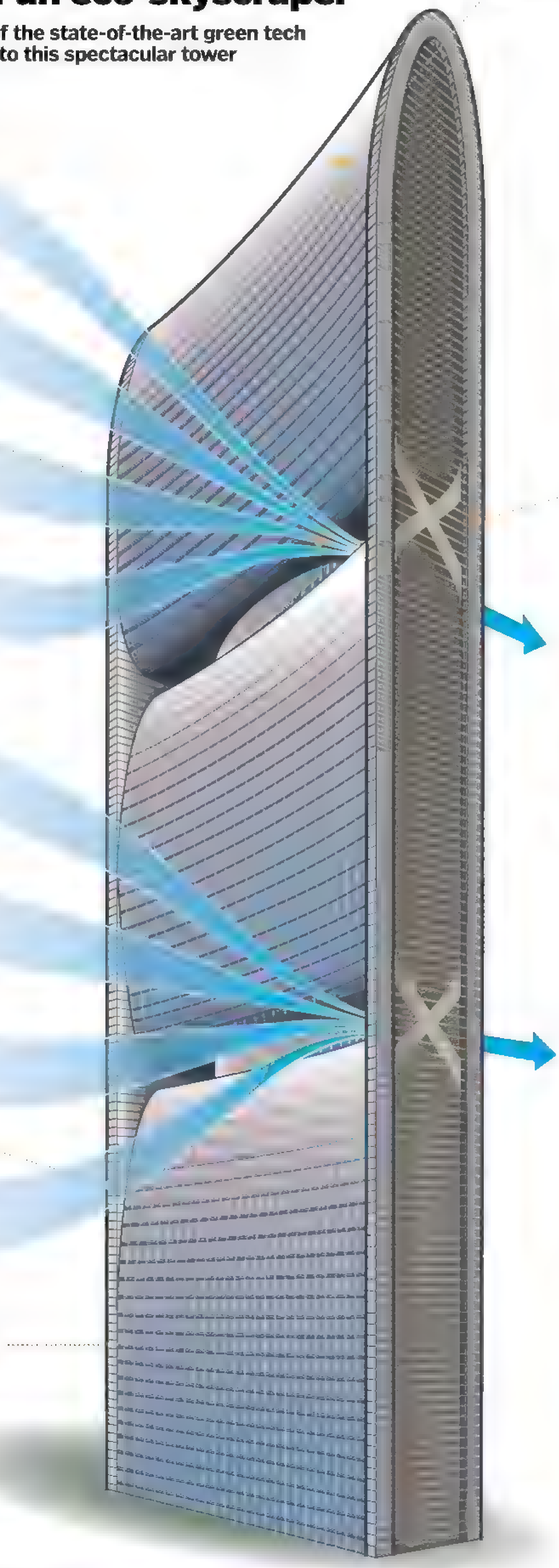
THE STATS
PEARL RIVER TOWER

HEIGHT	309m
NUMBER OF FLOORS	71
TOTAL FLOOR AREA	212,165m²
SITE AREA	10,635m²
NUMBER OF ELEVATORS	29
YEAR OPENED	2012

DID YOU KNOW? *Famous American architect Gordon Gill was the lead designer behind the Pearl River Tower*

Anatomy of an eco-skyscraper

Take a look at some of the state-of-the-art green tech that's been packed into this spectacular tower



Turbine inlet
Prevailing northerly and southerly winds are drawn through four inlets in the building's façade (two on either side) into a series of wind turbines. These produce electricity for use in the building's offices.

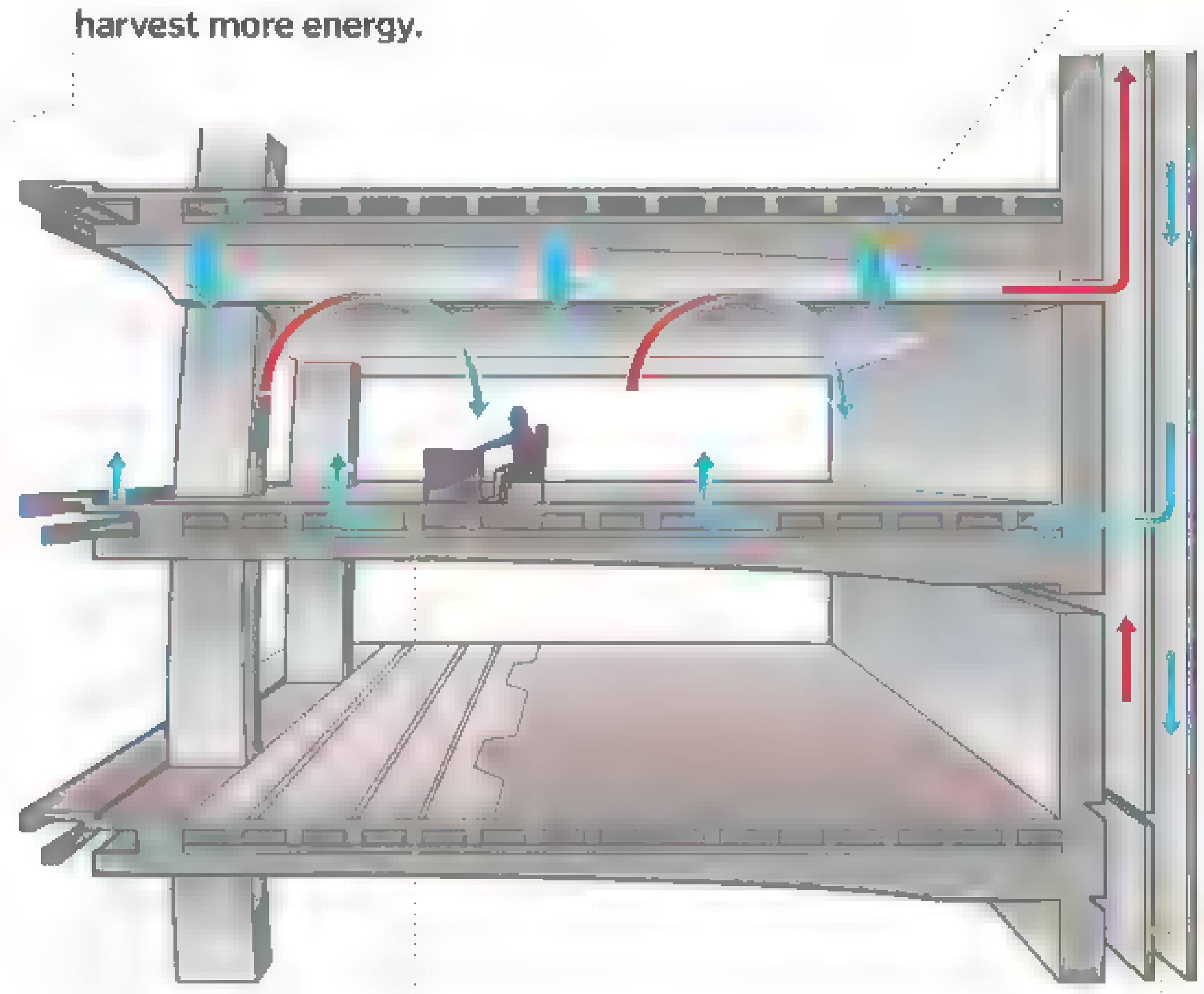
Triple glazing
On the eastern and western faces (the thin ends) a triple-glazed coating is used to prevent heat loss from within and excess heat from the Sun's rays entering.

Photovoltaic cells
A photovoltaic energy capture system is integrated into the Pearl River Tower's external shading system (blinds) and glass outer skin. As with the solar panels, this system can convert sunlight into electricity.

Solar panels
The roof of the Pearl River Tower is fitted with a large, curved array of solar panels. These panels soak up sunlight and generate electricity – the energy being used to power the building's automatic blinds.

Ventilation system
Air drawn into the building through its four main inlets is also rerouted into the structure's ventilation system. This can then be used to cool the ambient temperature of the office space so air conditioning is not needed in the summer.

Vertical axis
The vertical axes of the tower combine to grant it a revolutionary curvilinear form that both funnels approaching wind into the façade's turbine inlets as well as exploiting the area's solar path to harvest more energy.



Heat exchanger
Installed in the tower's mechanical floors, the heat exchangers receive heat from the double skin cavities and converts it for reuse as electricity or stores it for later use in underfloor heating.

Double skin
On the building's two vertical axes a two-layer façade traps hot air generated by the Sun in a thin cavity. The hot air, rather than seeping into the office space, rises to heat exchangers located on mechanical floors.

Turbine technology
The turbines equipped between the mechanical floor spaces of the Pearl River Tower can generate in excess of four per cent of the building's total power draw annually. This is due to the turbines being specifically designed to work across a variety of wind speeds, ranging from small flows moving at around eight kilometres (five miles) per hour, right up to intense 225-kilometre (140-mile)-per-hour surges. Due to the building's orientation, the prevailing winds from the north and south of Guangzhou City are harnessed, with the tower's curvilinear form funnelling indirect wind flows into the turbine inlets.

> "It was controlled from a central position, with its two crew positioned back to back"

The first electric submarine

Learn about the Goubet I – the earliest underwater vessel to be electrically powered

The Goubet I submarine was a two-person, electric submarine built by French inventor Claude Goubet in 1885. Manufactured in Paris, the sub has gone down in history as the first to be electrically powered, with a brace of cutting-edge tech advancing more primitive models.

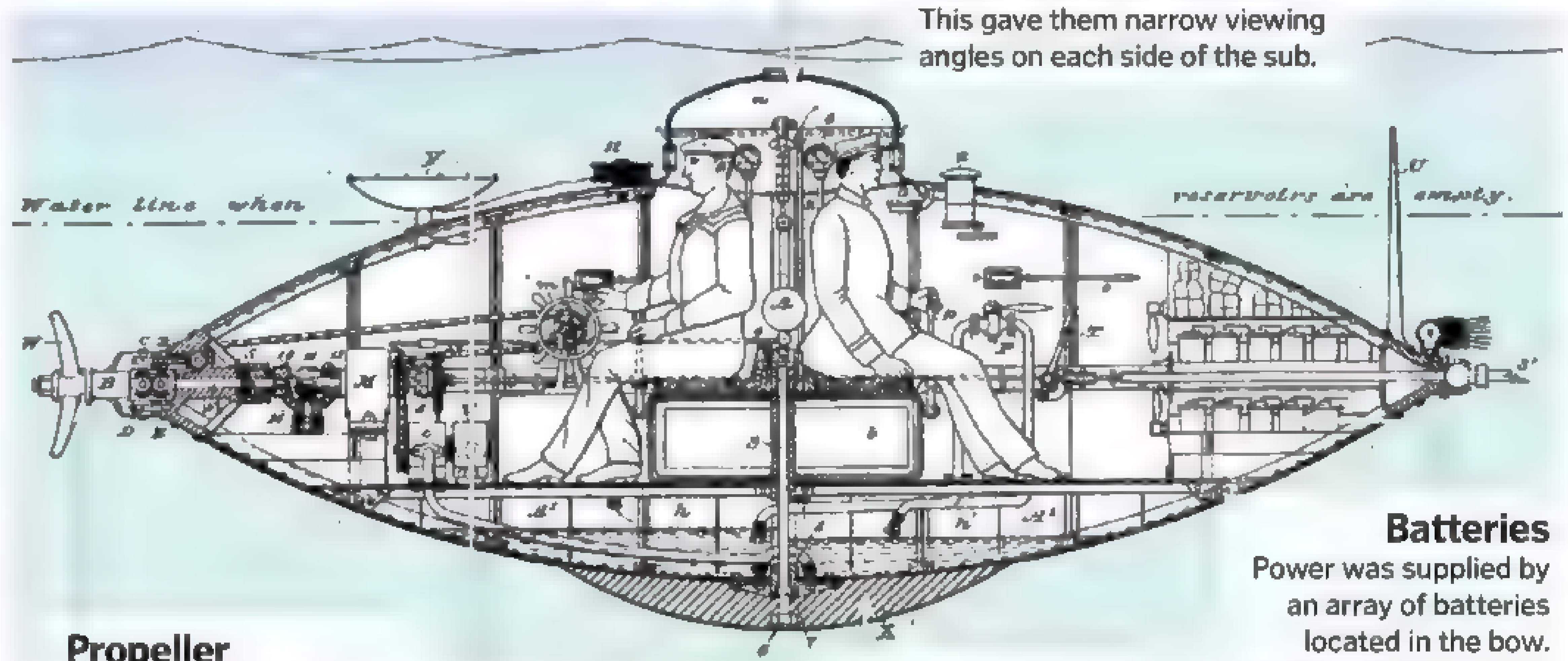
The Goubet I was battery powered, utilised a Siemens electric motor to drive its propeller and power a navigation light, and measured five metres (16.4 feet) long. The craft weighed in at just over six tons. It was controlled from a central position, with its two crew positioned back to back, seeing out of the vessel via small glass windows; they could see up, down and to the sides to some extent thanks to prisms.

After testing in the River Seine in Paris, however, the Goubet I was ultimately deemed a failure, because the submersible wasn't able to maintain a stable course or depth while moving forward. As a result, while some of its innovative technology lived on in later designs, the Goubet I itself was quickly scrapped.

Tour of the Goubet I

Take a peek inside the first sub that ran on electricity and learn why it failed

Tower
The crew saw out of the Goubet I via a series of windows and prisms in the conning tower. This gave them narrow viewing angles on each side of the sub.



Batteries
Power was supplied by an array of batteries located in the bow. These sent electricity to the pumps and lights.

Propeller
The sub did not have a rudder or dive planes, instead being fitted with a 'Goubet joint' - a mechanism that allowed the propeller to be redirected for steering.

Mine
Quickly commandeered for military ends, the Goubet I could carry a single mine which was released via a wire.

Ballast tanks
Stability was supposed to be ensured by a ballast system that filtered a small quantity of water between the front and back of the vessel, but it didn't work.

The Leyden jar

A handy and portable way to bottle static electricity

The Leyden jar was invented by two men, Dutch physicist Pieter van Musschenbroek and Ewald Georg von Kleist, Dean of the Kamin Cathedral in Pomeranian, in 1745. Musschenbroek, based at the University of Leiden – also known as Leyden – kept better records and it became known as the Leyden jar.

The Leyden jar enables you to store static electricity for several minutes or even days. To discharge it you merely complete the circuit between the outer foil and the top of the rod. If, for example, you touch them you will receive a powerful electric shock that can cause serious injury.

In the 19th century they were used to experiment with electricity and promoted as 'cure-all' devices. These were the first capacitors, and the same principles are used for capacitors used today in amplifiers and radio equipment.

1. Brass rod
This is connected to a hand-cranked static generator or any other device that can supply electricity to it. This supply is removed when the jar is charged.

2. Stopper
Rubber, cork or wooden stopper insulates the rod from the glass jar.

3. Metal chain
The chain links the rod to the metal foil at the bottom of the jar. Here the electrical charge is unable to discharge because of the presence of the glass. Instead, the positive and negative electrons of the charge repel each other to the outer and inner metal foil. These forces stay in equilibrium until they are discharged.

4. Glass jar
Half-filled with water. The electrical charge was thought to be stored inside the water. It was also thought the glass jar retains the charge, but it is actually kept on the inside layers of the metal foil. The glass merely acts as an insulator or dielectric.

5. Metal foil conductors
A metal coating or foil is applied half-way up the inside and outside of the jar. The outside foil must be connected by wire to the ground.

5 TOP FACTS
PIEZOELECTRIC PRODUCTS

Watch
1 The reverse-piezoelectric effect is used in quartz watches in order to oscillate a crystal thousands of times per second and accurately keep time.

Microphone
2 By sticking a vibrating microphone to a piezoelectric crystal, sound energy is converted into electric signals that can be understood by a computer.

Record player
3 The diamond-tipped needle of a record player bumps up and down, hitting a small piezoelectric crystal and producing signals that are converted into sound.

Ultrasound
4 A piezoelectric device converts electricity into mechanical vibrations very quickly, producing ultrasound vibrations that can be used for things such as scans.

Gas lighter
5 A basic form of piezoelectricity allows a gas lighter to be [illegible] by hitting a small hammer against a piezoelectric crystal to produce a spark across a gap.

DID YOU KNOW? *French physicists Pierre and Paul-Jacques Curie discovered the piezoelectric effect in 1880*


Images © Science Museum

There is nothing static about your hair when it is introduced to static electricity

Static electricity – mystery solved

Static electricity is all about freewheeling subatomic particles

Atoms are bundles of neutrons and positively charged protons – the nucleus – orbited by negatively charged electrons. When an atom has more protons than electrons, it has a positive charge. Excess electrons give an atom a negative charge. Particles and atoms with opposite charges are attracted to each other, and particles with the same charge repel each other.

When you rub a balloon against your hair, electrons from the hair atoms jump across to the balloon atoms, giving the balloon a stationary negative charge, or 'static electricity'. If you put the balloon against a wall, the negatively charged balloon atoms repel the negatively charged electrons from the wall atoms. As a result, atoms along the wall surface end up with a positive charge that attracts the negatively charged balloon atoms. The balloon then 'sticks' to the wall until the electrons redistribute themselves, giving the balloon a neutral charge.

Piezoelectricity

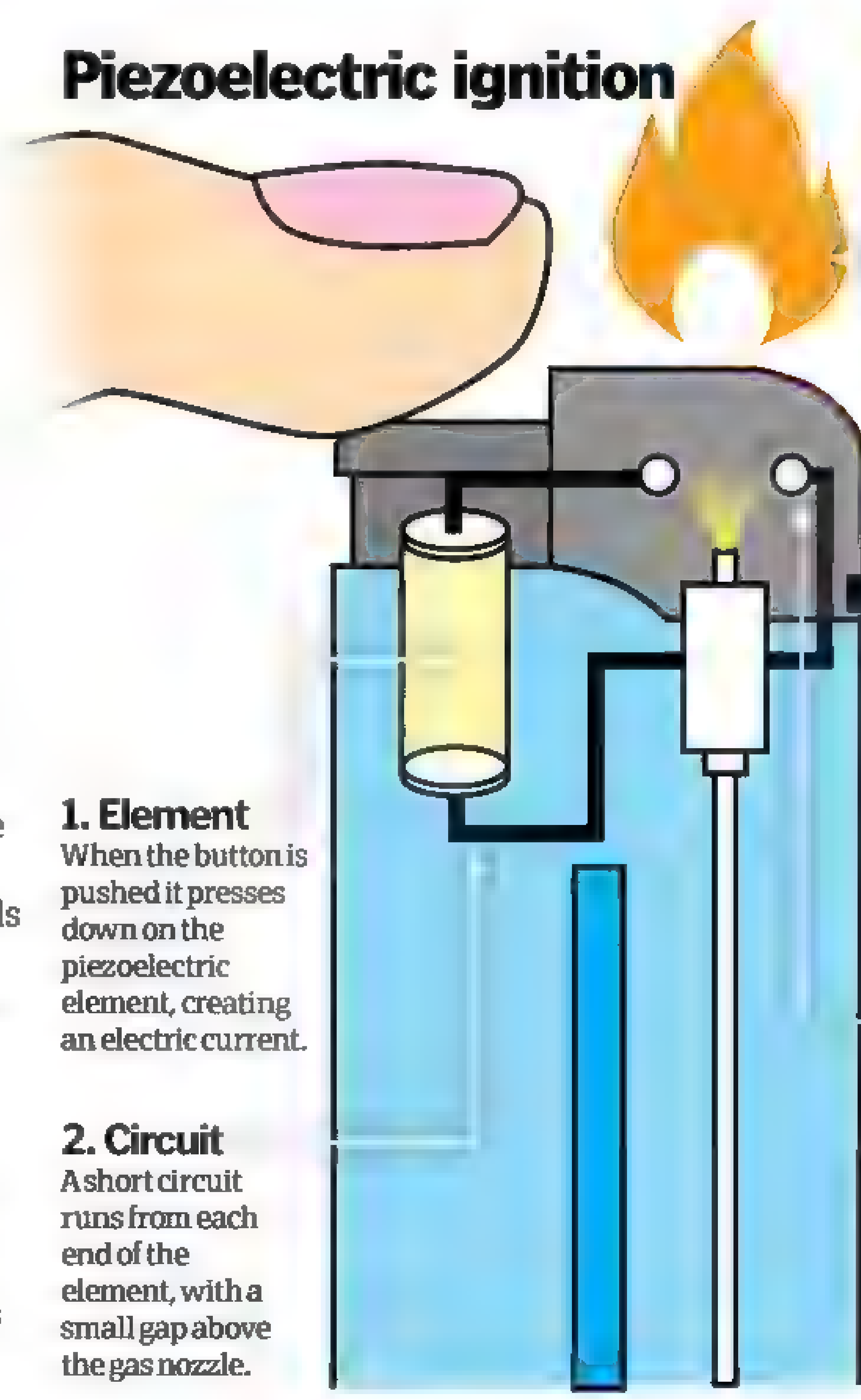
Products such as gas lighters employ piezoelectricity in order to produce a flame


Together with his brother, Paul-Jacques, Pierre Curie (pictured) discovered piezoelectricity

A piezoelectric material is one that is able to generate an electric charge when it is subjected to mechanical stress. Oppositely, when electricity is applied it will start vibrating, both of which are useful properties used in a variety of products such as gas lighters and speakers. It is often crystalline materials such as quartz that exhibit this behaviour.

We usually imagine a crystal as a rigid structure with atoms arranged in a symmetrical grid-like shape, a unit cell. However, in piezoelectric crystals the atoms are not uniformly arranged, but their electric charges are balanced. Squeezing the crystal moves some of the atoms closer and further apart, which changes the balance of positive and negative charges and ultimately creates an electric current across the crystal, from positive at one end to negative at the other. On the other hand, if you run a voltage across the crystal, the atoms move to rebalance their electric charges and the crystal 'vibrates'.

Piezoelectric ignition



1. Element
When the button is pushed it presses down on the piezoelectric element, creating an electric current.

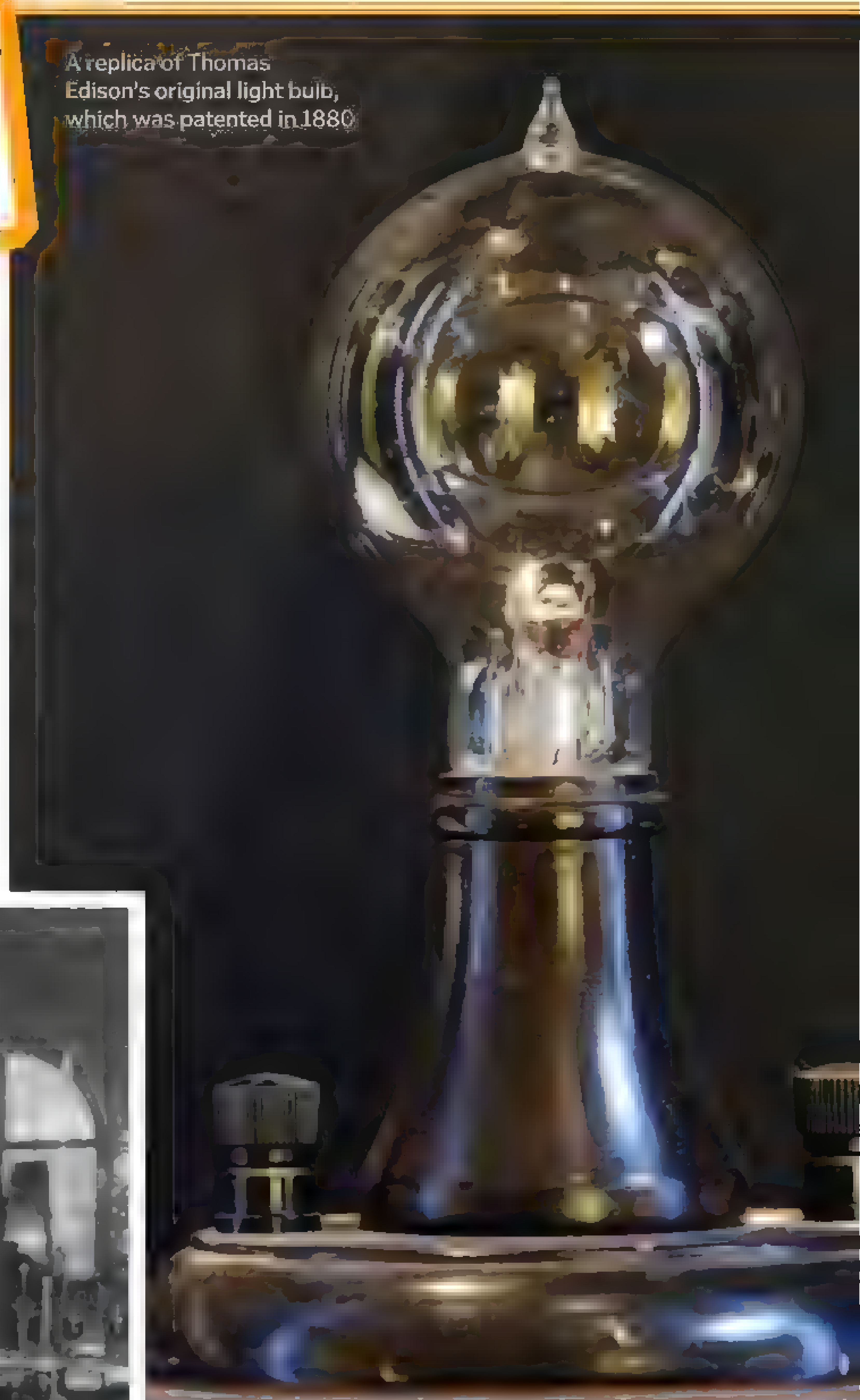
2. Circuit
A short circuit runs from each end of the element, with a small gap above the gas nozzle.

3. Electric arc
As current flows around the circuit, it breaks the gap by becoming an electric arc and jumping across.

4. Flame
Gas released from a small nozzle ignites as it comes into contact with the electrical arc and produces a flame.

The electric light bulb

HIW sheds some light on one of the most world-changing inventions

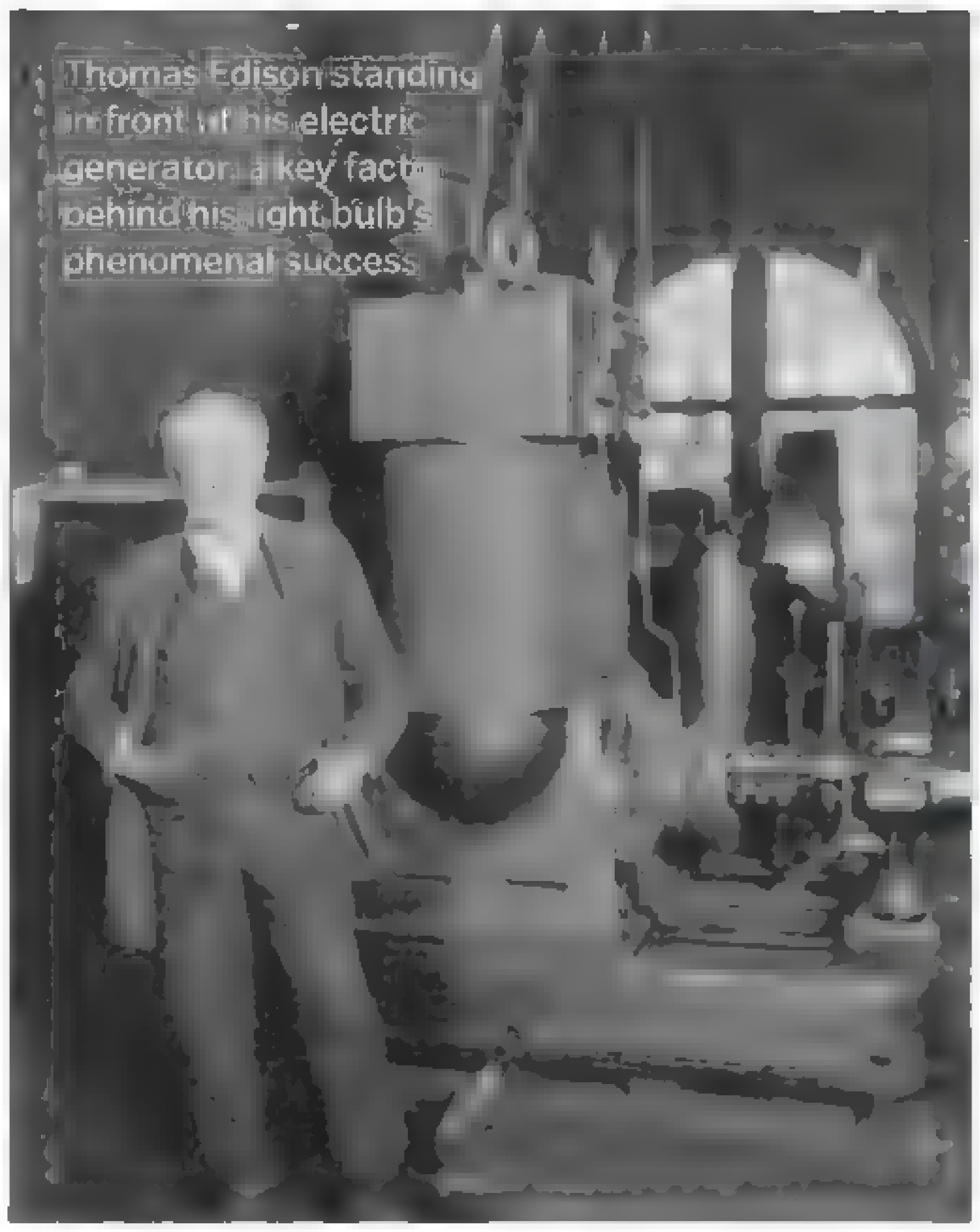

A replica of Thomas Edison's original light bulb, which was patented in 1880

Today the electric light bulb is an essential part of society, with virtually all streets, homes and vehicles installed with one. The invention has literally lit up the Earth and transformed how we live.

The beginning of the journey to the electric light bulb began in 1799 when Italian physicist Alessandro Volta invented the voltaic pile (battery). The details of the battery soon spread through Europe, with many scientists replicating it and experimenting with its power-giving capabilities. One of the most notable of these scientists was British physicist Sir Humphry Davy who built one at the Royal Institution in 1802. In 1810, after much experimentation, Davy invented the first arc lamp, a temporary electric light source enabled by connecting two carbon rods to the battery's terminals and bringing them to within a couple of millimetres of each other. This caused the electric current to jump between the two, creating a bright plasma stream that illuminated the immediate surrounding area.

Unfortunately, the intensity of the plasma soon caused the carbon rods to burn away and the invention did not gain commercial traction. However, the use of carbon and a variety of other metals as electrodes and filaments did, leading a number of scientists to create crude lights. None were sustainable, however.

The next major breakthrough came in the realisation that the electrodes/filaments used in incandescent lights could be protected from quick destruction by placing them within a vacuum filled with an inert gas (as demonstrated by Warren de la Rue in 1840). This, along with the later discovery that filaments could be carbonised, allowed basic light bulbs to be created that, rather than lasting seconds or minutes, would work for hours and eventually days. Indeed, throughout the mid-19th century numerous scientists, and even an illusionist, showed such bulbs to their friends and at public demonstrations.


Thomas Edison standing in front of his electric generator, a key factor behind his light bulb's phenomenal success

This series of prototypes culminated in 1879 when Joseph Swan successfully demonstrated and then sold a light that used a single coil of carbonised artificial cellulose fibre embedded within an airless glass bulb. This was the first commercially sold incandescent light bulb. Critically though, its adoption was only on a very small scale as, despite the bulb proving resilient, the power source needed was largely unavailable, with no electric infrastructure in place to support a wide-scale rollout.

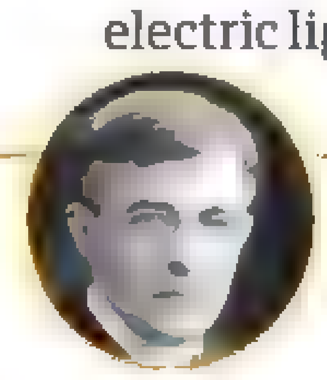
This set the scene for Thomas Edison, who in 1880 successfully patented his own light bulb, which aside from being an improved design to that of Swan, was backed up by Edison's own electric generator, a package that would enable him to largely corner the new market for electric lighting that was set to take off.

Light bulb evolution

After Thomas Edison brought light bulbs to the mass market, what happened next?

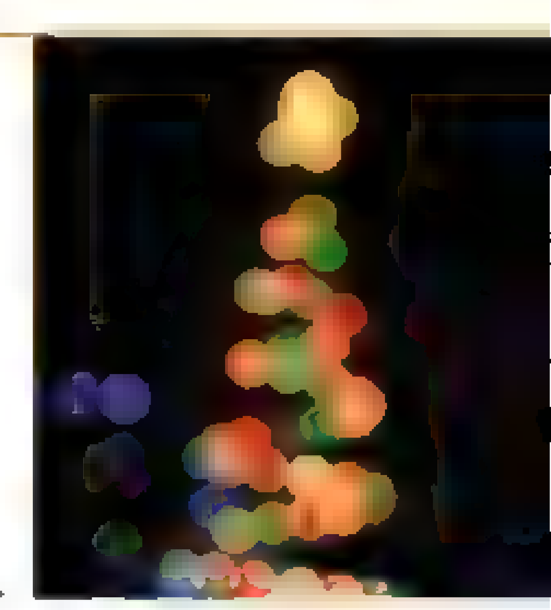
1903
Tantalum
After the carbon rod light bulb, scientists test new filament materials to improve brightness. In 1903 Siemens and Halske try using tantalum.

1906
Sinter-lating
The General Electric Company, which was cofounded by Thomas Edison, patents a method of making filaments from sintered tungsten.



1913
Inert
American physicist Irving Langmuir discovers that filling bulbs with inert gas rather than just a vacuum results in twice the luminous efficacy.

1917
Festive lighting
Electric Christmas lights see a boom in 1917 when teen Albert Sadacca is inspired to start making them after a fire in NYC caused by candles in a tree.



Inside a carbon filament light bulb

We take a look at Thomas Edison's 1880 electric lamp, arguably the first fully functioning light bulb

Carbon spiral
Edison used a carbonised (achieved by heating it to high temperatures), high-resistance filament, which was coiled in the centre by winding it around a bobbin.

Filament ends
As the filament coil was very thin and delicate it could not be attached to the platinum lead wires directly. Instead lamp-black and tar were used at the ends as a mould around each connection, ensuring its stability.

Clamps
The platina wires were attached to the platinum lead wires with two mini clamps encased in the bulb.

Leading wires
The light bulb's leading wires were made out of platinum due to its high melting point of 1,772°C (3,222°F) and low resistance compared to the filament.

Vacuum tube
To create a vacuum within the bulb a vacuum tube was blown that attached to a pump. After exhaustion, this entrance was hermetically sealed.

Platina wires
The carbon filament was not directly attached to the platinum lead wires via the lamp-black and tar mould. Instead two platina contact wires were used.

Vacuum bulb
The bulb for the filament was roughly spherical and made from glass. The inside was a vacuum – something achieved by drawing out the oxygen through a top-mounted vacuum tube.

Copper wires
Electric current for the light bulb was supplied from a battery/generator through conventional copper wires.

Top 5 facts: light bulbs

1

2

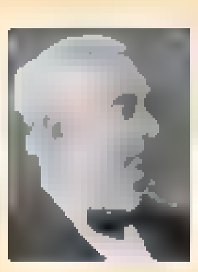
3

4

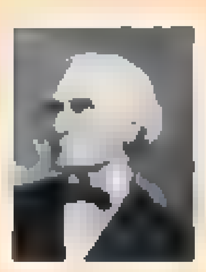
5

Bright sparks: the race to the commercial light bulb

Sir Humphry Davy
In 1802 British scientist Sir Humphry Davy used his large battery to pass a current through a thin strip of platinum. The experiment worked, but the platinum did not glow very brightly and wore out too quickly to be practically implemented into a lamp.



Warren de la Rue
In 1840 chemist and astronomer Warren de la Rue enclosed a platinum coil in a vacuum tube and passed an electric current through it. This was one of the first true light bulbs as we know them today, however its cost and complexity made it impractical to roll out.



Jean Robert-Houdin
This illusionist created his own incandescent light bulbs and showed them publicly at his estate in 1852. Again, they were curiosities and no practical production process or cost-efficient materials meant they couldn't be produced commercially.

Alexander Lodygin
In 1872 Russian Lodygin obtained a patent for an incandescent light bulb that used carbon rods in a nitrogen-filled, sealed bell glass receiver. He later moved to the US and applied for many patents, showing a molybdenum filament at the Paris World's Fair in 1900.

Joseph Swan
This British physicist arguably created one of the first sustainable light bulbs, demonstrating his carbon rod bulbs in 1878-9. He received a patent and began installing them in a few homes and theatres. He later partnered with Edison and set up the Ediswan Electric Company.

1937
Krypton-light
Factory production of light bulbs filled with the noble gas krypton, invented by Imre Bródy, begins in Hungary.

1977
Energy saving
Energy-saving light bulbs begin to be introduced to the market, leading to the generation of compact fluorescent lamps.

1991
Long-lasting
The electronics company Philips produces a fluorescent light bulb that lasts 60,000 hours through the process of magnetic induction.

2010
Green light
In many countries worldwide incandescent light bulbs begin to be phased out in favour of more eco-friendly LED and fluorescent types.

2012
Lights out
From 1 September, an EU directive bans all retailers from selling incandescent bulbs. It's hoped this will save an annual 39 terawatt hours by 2020.

> "A fork of lightning tearing across the sky is one of the most vivid depictions of electrical current"

Electricity in nature

Electricity has been a fundamental part of human civilisation for over a hundred years, but nature got there well before us.

A fork of lightning tearing across the sky is one of the most vivid depictions of an electrical current, but lightning also exemplifies one of electricity's other faces: static. While electric current is all about moving charges, static electricity is the buildup of charge in one place. In the case of lightning, opposite charges accumulate at the base of a storm cloud and on the ground, generating an increasingly powerful potential difference which is eventually discharged in a blaze of light.

We often witness slightly less spectacular forms of static in the form of little electric shocks. When different materials come into contact, they frequently steal electrons from each other, with some holding on to this charge better than others. The simple act of walking across carpet or taking off a jumper can thus cause your body to accumulate a negative charge. When you touch a conductive object like a door handle, the excess electrons can escape through your fingertips, startling you with an electric shock in the process. Moisture in the air helps to dispel static charges, making these shocks far more common in dry weather.

Static may be a minor inconvenience, but your body – like those of all living creatures – can't function without electricity. Right now, tiny electric impulses are racing through you, relaying messages to and from your brain through a dense network of neurons. These cells create an electric potential by controlling the flow of charged ions across their membranes. When stimulated, they reverse this potential, passing on a signal.

Through these electrical impulses, your nerves alert your brain to pain but also convey the multitude of sensations captured by sight, sound, taste, touch and smell. Analysing this input, your brain then uses the same means of communication to tell your muscles to contract, controlling conscious movement but also the subconscious working of organs such as the heart. Unlike the slow-paced chemical communication of, say, hormones, electric impulses allow these important messages to be transmitted almost instantaneously.

The voltages generated by your body are no greater than 0.1 volts, but some animals have evolved far more sophisticated systems to produce electricity. Electric eels, for instance, deliver powerful jolts to stun prey or deter predators. One of numerous electric fish species, they achieve this thanks to as many as 6,000 electrocytes – disc-shaped cells which generate an electric potential. Each of these cells creates a tiny internal negative charge by pumping out positively charged ions.

Under the brain's instructions, an electrocyte opens channels which allow positive ions back in, but only on one side of the cell, creating a temporary electric potential across the cell. By stacking up all these tiny batteries and firing them in unison, the electric eel can create an imposing 650-volt shock – more than enough to put a would-be assailant off its lunch.

Other aquatic animals such as sharks have taken a different approach, tuning in to the faint electrical signals emitted by their prey in the water. Since all animals' brains and bodies use electricity, it's an effective way to track down just about any creature in murky waters.

The secrets of lightning

Delve into a storm to get to grips with Mother Nature's most powerful display of electricity

7 strikes

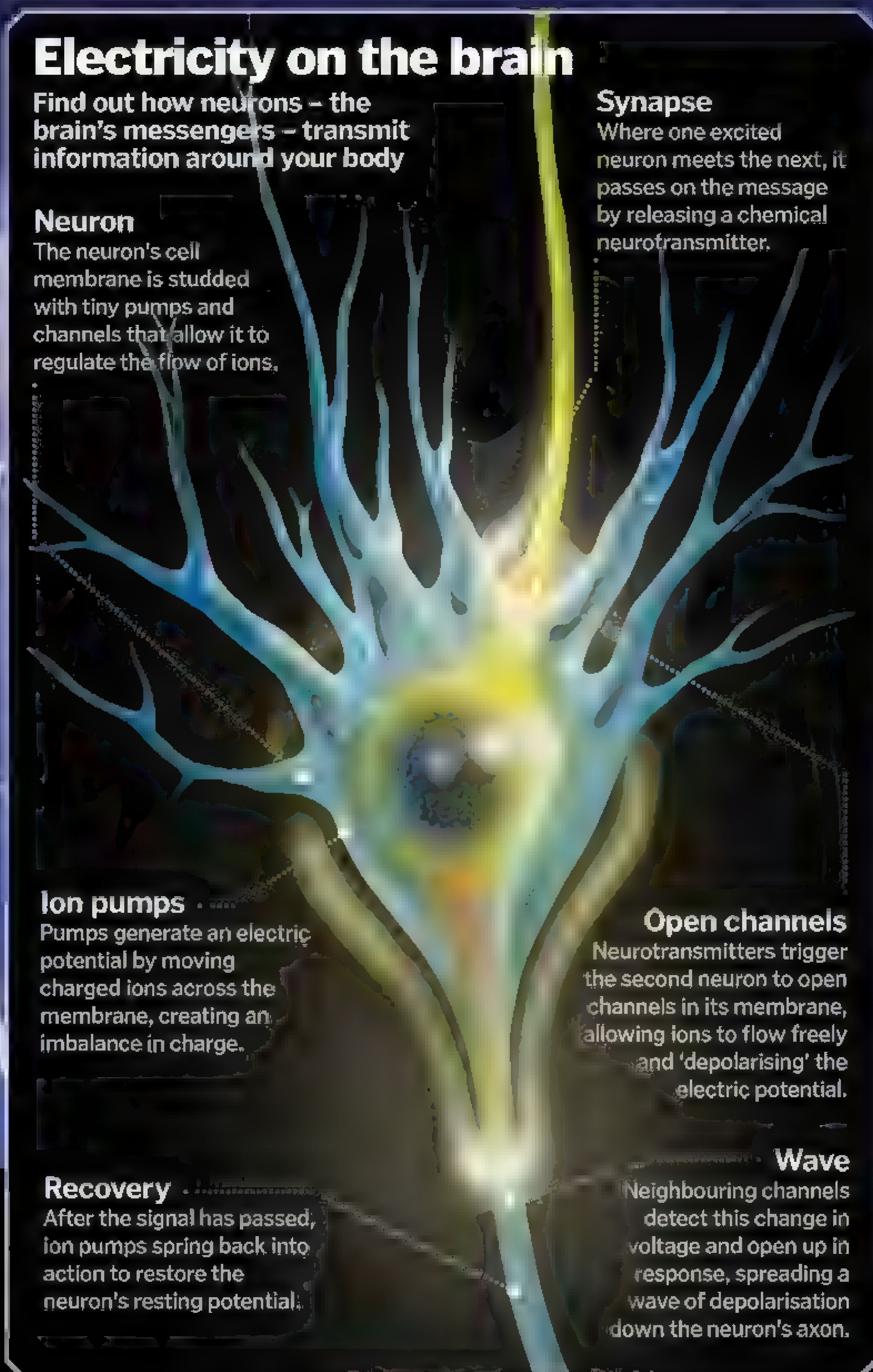
THE HUMAN LIGHTNING ROD

The chances of getting hit by lightning are incredibly small (about 1:10,000 over a lifetime), but odds-defying US park ranger Roy Sullivan survived seven separate strikes over just 35 years.

Lightning bolts produce the highest naturally occurring temperatures on Earth, roughly 30,000°C (54,000°F)

Electricity on the brain

Find out how neurons – the brain's messengers – transmit information around your body



Neuron
The neuron's cell membrane is studded with tiny pumps and channels that allow it to regulate the flow of ions.

Synapse
Where one excited neuron meets the next, it passes on the message by releasing a chemical neurotransmitter.

Ion pumps
Pumps generate an electric potential by moving charged ions across the membrane, creating an imbalance in charge.

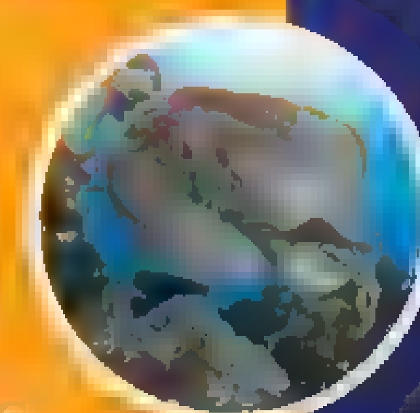
Open channels
Neurotransmitters trigger the second neuron to open channels in its membrane, allowing ions to flow freely and 'depolarising' the electric potential.

Recovery
After the signal has passed, ion pumps spring back into action to restore the neuron's resting potential.

Wave
Neighbouring channels detect this change in voltage and open up in response, spreading a wave of depolarisation down the neuron's axon.

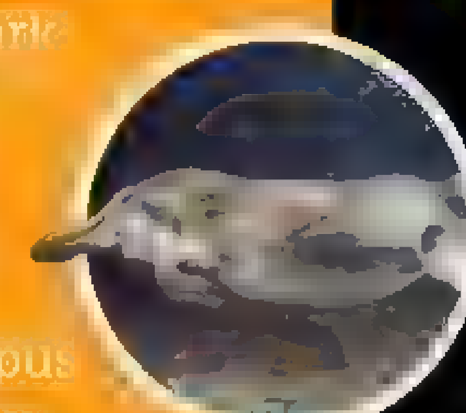
Electrifying animals

Electric eel
Perhaps the most famous of electric critters, the electric eel is not actually an eel but a freshwater fish native to South America. The fish gets its spark from electricity-generating cells which make up a whopping 80 per cent of its body volume.



Electric ray
The electric ray family is the largest animal group with the power to generate electric shocks, comprising 69 different species. Rays can deliver currents of up to 30 amperes and voltages of 50-200 volts.

Hammerhead shark
Sharks have mastered the art of electroreception, detecting the weak electrical currents generated by their prey's muscular contractions. Voltages down to just one-billionth of a volt are picked up by special pores dotted across their faces. The hammerhead's odd noggin packs in more of these pores than any other shark.

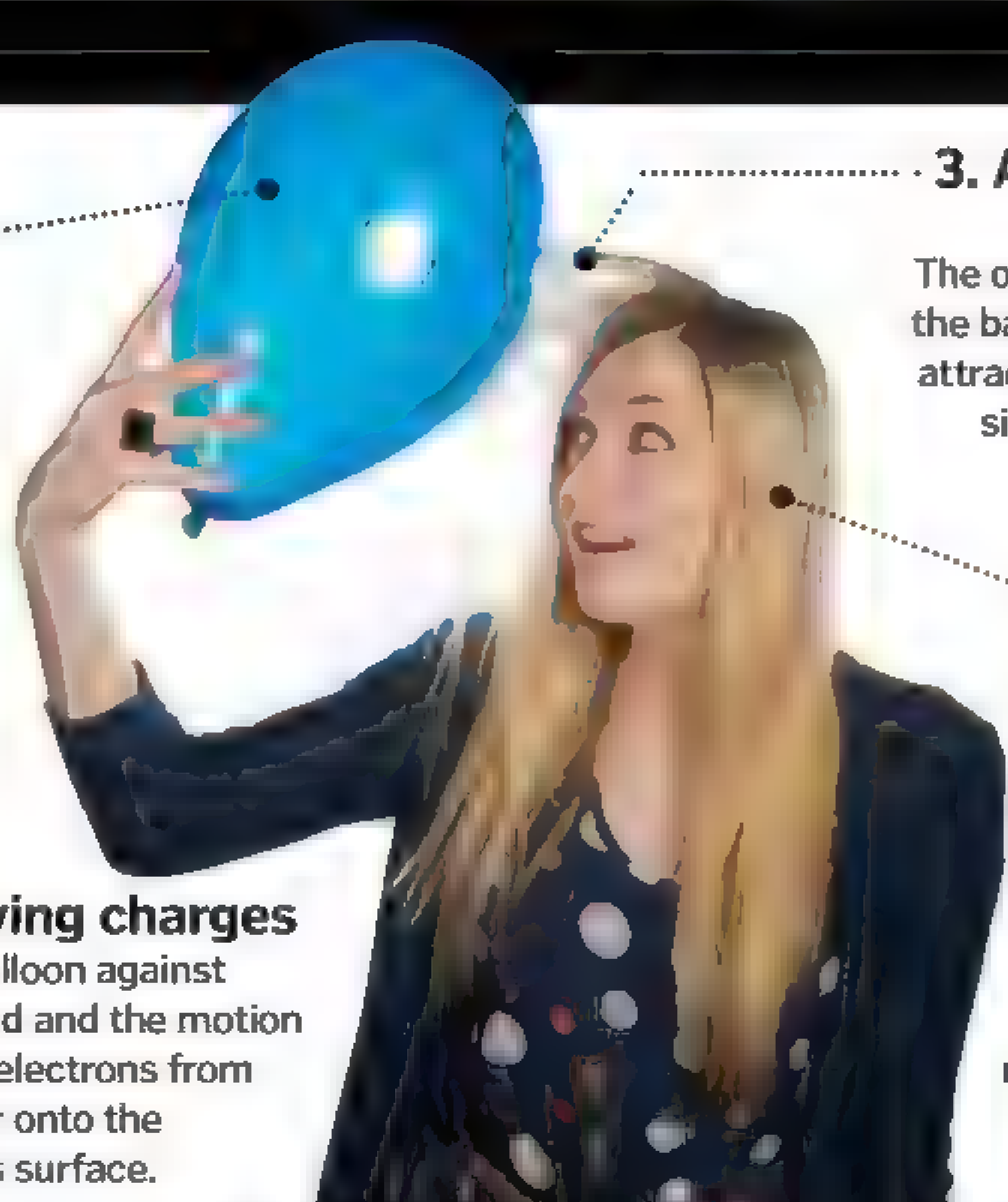


Duck-billed platypus
Along with the echidna, the platypus is one of the very few mammals to detect dinner using electricity. Hunting underwater, the platypus closes its eyes, nose and ears, relying instead on the 40,000 electroreceptors in its bill to locate victims. By swaying its head from side to side it can very accurately pinpoint prey.

Uses of static

Static electricity is well known for its party tricks, but it has numerous practical uses as well. Laser printers and photocopiers project an image onto a positively charged plate, allowing charge to leak away from lighter parts of the image. Negatively charged black toner then sticks to the dark areas of the image before being transferred onto paper.

Similarly cars are often spray-painted with a positively charged gun, while the vehicle itself is negatively charged, attracting an even layer of paint. Static electricity can even be used to save lives – defibrillators utilise the electrical discharge between two charged paddles to kick-start flagging hearts.



1. Moving charges
Rub a balloon against your head and the motion sweeps electrons from your hair onto the balloon's surface.

2. Opposite charges
The extra electrons give the balloon a negative charge but leave your hair positively charged.

3. Attraction and repulsion
The opposing charges of the balloon and your hair attract each other, while single strands of hair repel each other.

"The low-frequency magnetic fields used don't interact with people or pets, making this tech safe to use"

Wireless electricity

Find out how new technology is set to make power cables a thing of the past

Own an electric toothbrush? Then you already have wireless electricity at home. Toothbrush chargers use inductive coupling to provide power without electrical contacts. When current from the mains runs through a coil of wire in the charger unit, it produces a fluctuating magnetic field which induces a current in a second coil embedded inside the toothbrush. This principle also underlies charging mats which power up phones and cameras at close range.

The catch, however, is that inductive coupling is only effective over a very short range – indeed, stray by just a few millimetres and the magnetic field tails off rapidly.

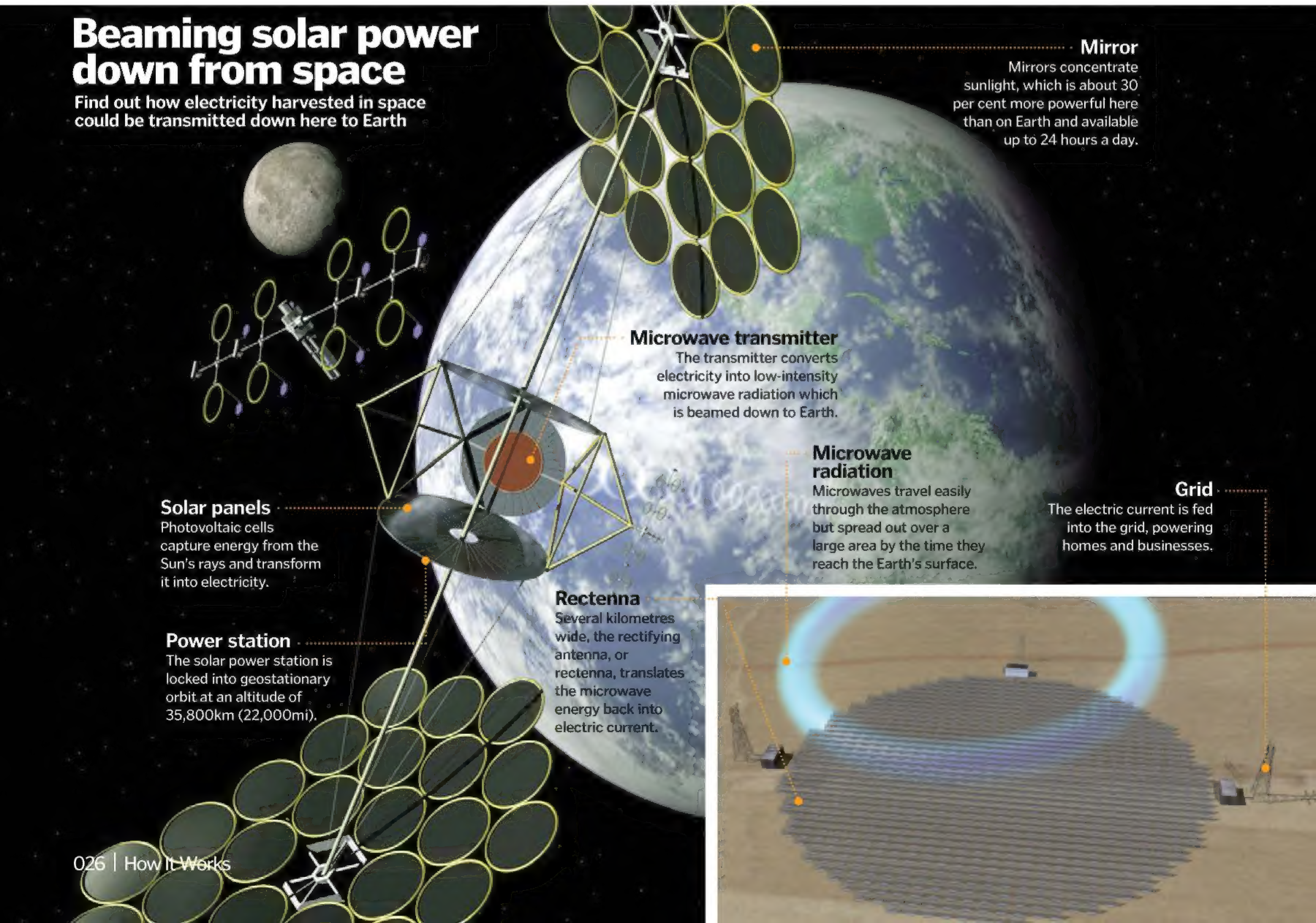
One solution is to throw resonance into the mix. Resonance is the phenomenon which enables an opera singer to shatter a wineglass with their voice alone. For this to happen, the frequency of the singer's voice has to match the glass's innate resonant frequency – the rate at which the glass naturally vibrates.

To apply this idea to wireless electricity, scientists fine-tune two coils to resonate to the same frequency of magnetic field. This makes transmission across a few metres possible as the second coil amplifies the energy of the first.

The low-frequency magnetic fields used don't interact with people or pets, making this tech safe to use in a domestic environment.

If you want to beam power over much greater distances though, converting energy into electromagnetic radiation (for example, light or microwaves) is the way to go. Laser-transmitted power has already been used to power unmanned aircraft. First, electricity is converted into a high-powered infrared laser beam; a photovoltaic cell at the other end then turns this back into electrical current.

Microwave-transmitted power follows much the same idea, converting energy into microwaves then back into current with the aid of a rectifying antenna, or rectenna. Although this is more efficient than laser beams it does require much bulkier equipment.



KEY DATES
GOING WIRELESS

1893
Nikola Tesla publicly demonstrates wireless electricity for the first time, though it's quite inefficient.

1968
Peter Glaser suggests wirelessly transmitting solar energy captured in space and space-based solar power is born.

2003
NASA scientists fly a lightweight unmanned aircraft powered solely by a ground-based laser.

2007
Researchers at MIT power a light bulb wirelessly over a distance of 2m (6.6ft), with 40 per cent efficiency.

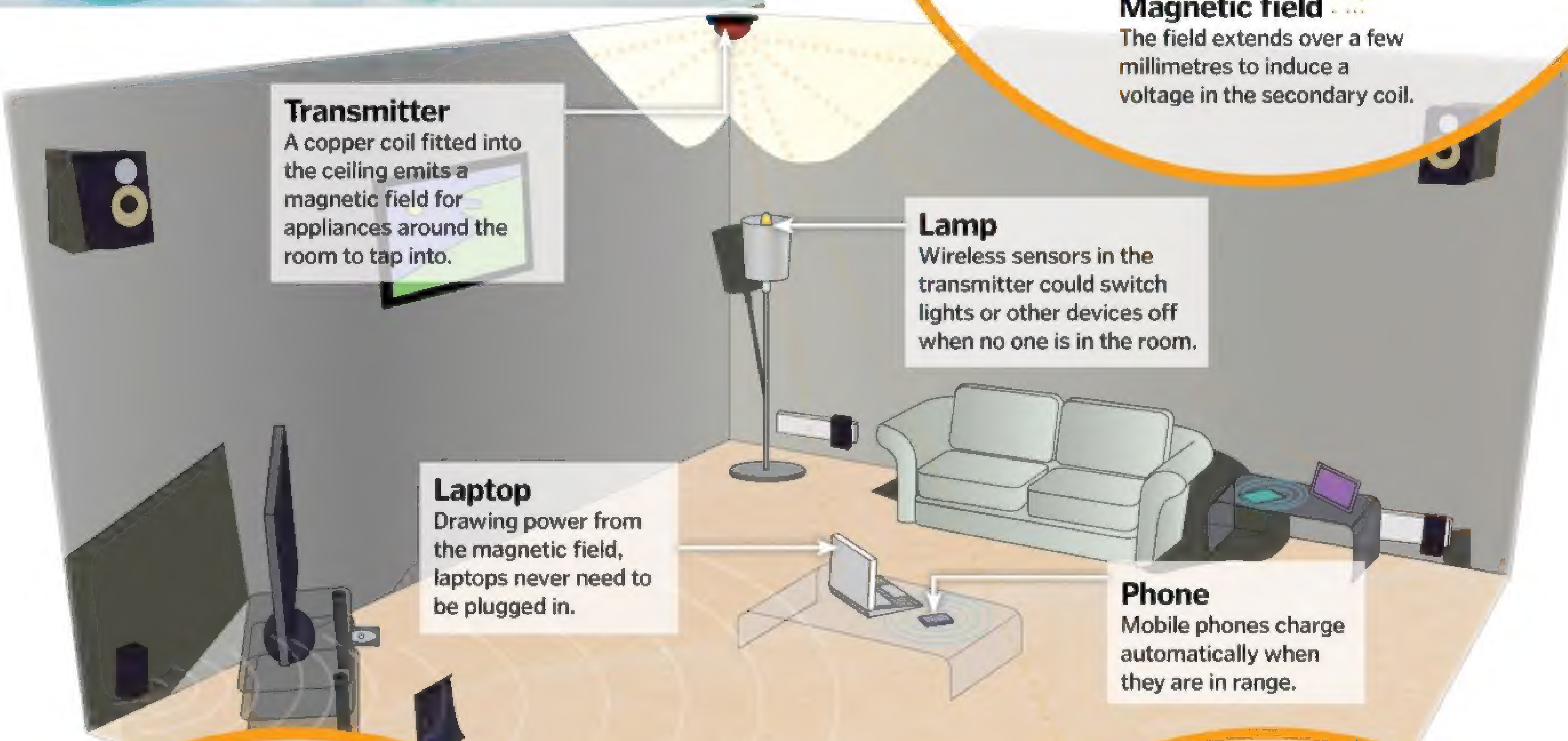
2009
US company Powermat launches the first commercially successful wireless charging mats.

DID YOU KNOW? *Tesla devised a system that would transmit power wirelessly across the globe, but didn't get funding for it*

Wireless electricity at home

How wireless electricity could rid our homes of those pesky power cables

A common example of wireless electricity in the home is the electric toothbrush which uses inductive coupling technology



Transmitter
A copper coil fitted into the ceiling emits a magnetic field for appliances around the room to tap into.

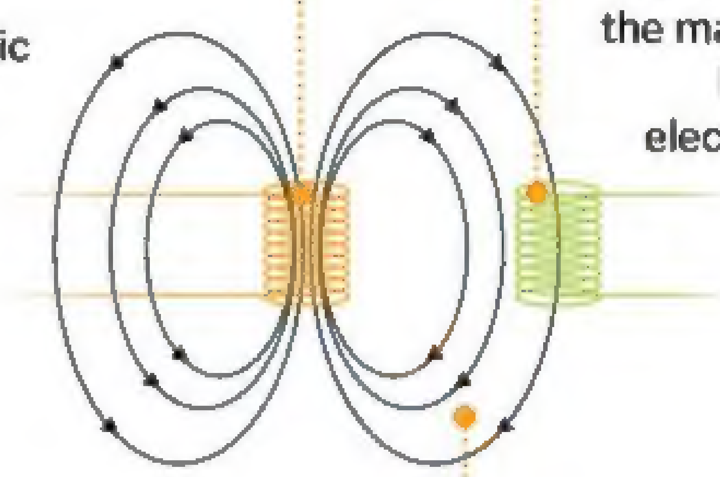
Lamp
Wireless sensors in the transmitter could switch lights or other devices off when no one is in the room.

Laptop
Drawing power from the magnetic field, laptops never need to be plugged in.

Phone
Mobile phones charge automatically when they are in range.

Inductive coupling

Used in phones, charging mats, toothbrushes



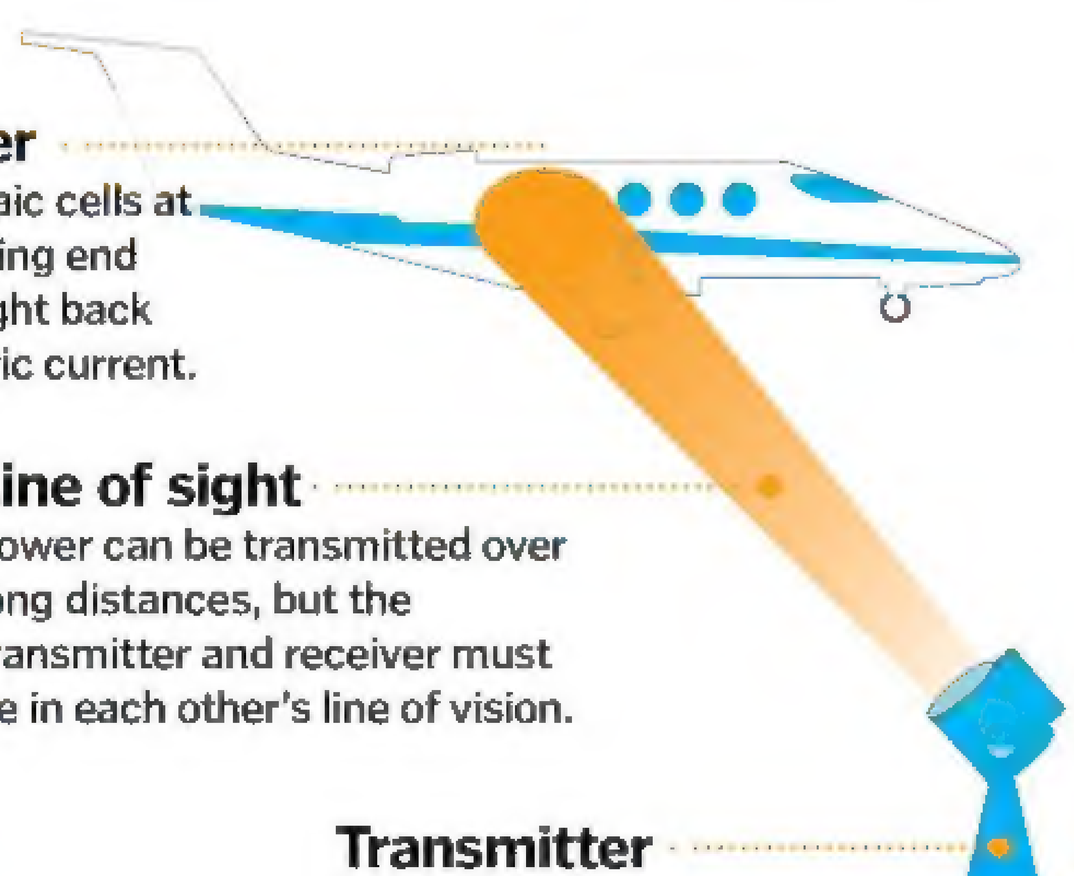
Transmitter coil
Connected to the power socket, this coil generates a magnetic field as alternating current travels through it.

Receiver coil
Inside the appliance, this coil converts the magnetic field back into an electric current.

Magnetic field
The field extends over a few millimetres to induce a voltage in the secondary coil.

Infrared radiation

Used in lamps, remote controls, ePhoto frames



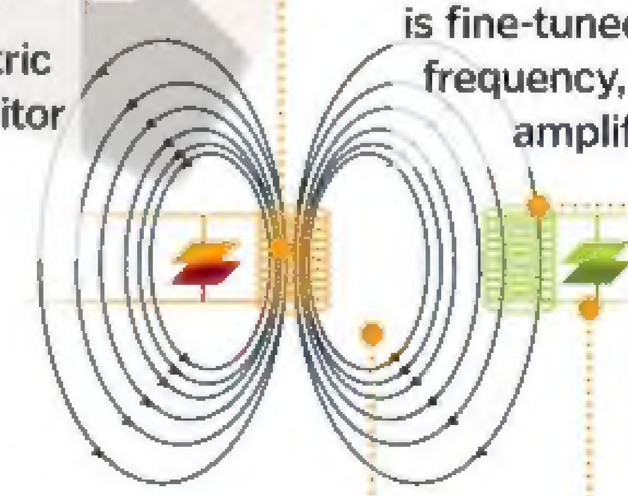
Receiver
Photovoltaic cells at the receiving end convert light back into electric current.

Line of sight
Power can be transmitted over long distances, but the transmitter and receiver must be in each other's line of vision.

Transmitter
Electricity is converted into a concentrated beam of infrared.

Resonant induction

Used in televisions, laptops



Transmitter
Energy oscillates between an electric field in the capacitor and a magnetic field in the coil.

Receiver
The receiving resonator is fine-tuned to the same frequency, allowing it to amplify the energy.

Transmission
This allows for power to be transmitted safely over 2-3m (6-9ft) and even through obstacles.

Current
An electric current is induced in the receiving coil.

> "The interaction of the magnetic field with the winding currents generates a usable force within the motor"

Electric motors

How do these widespread devices transform electrical energy into motion?

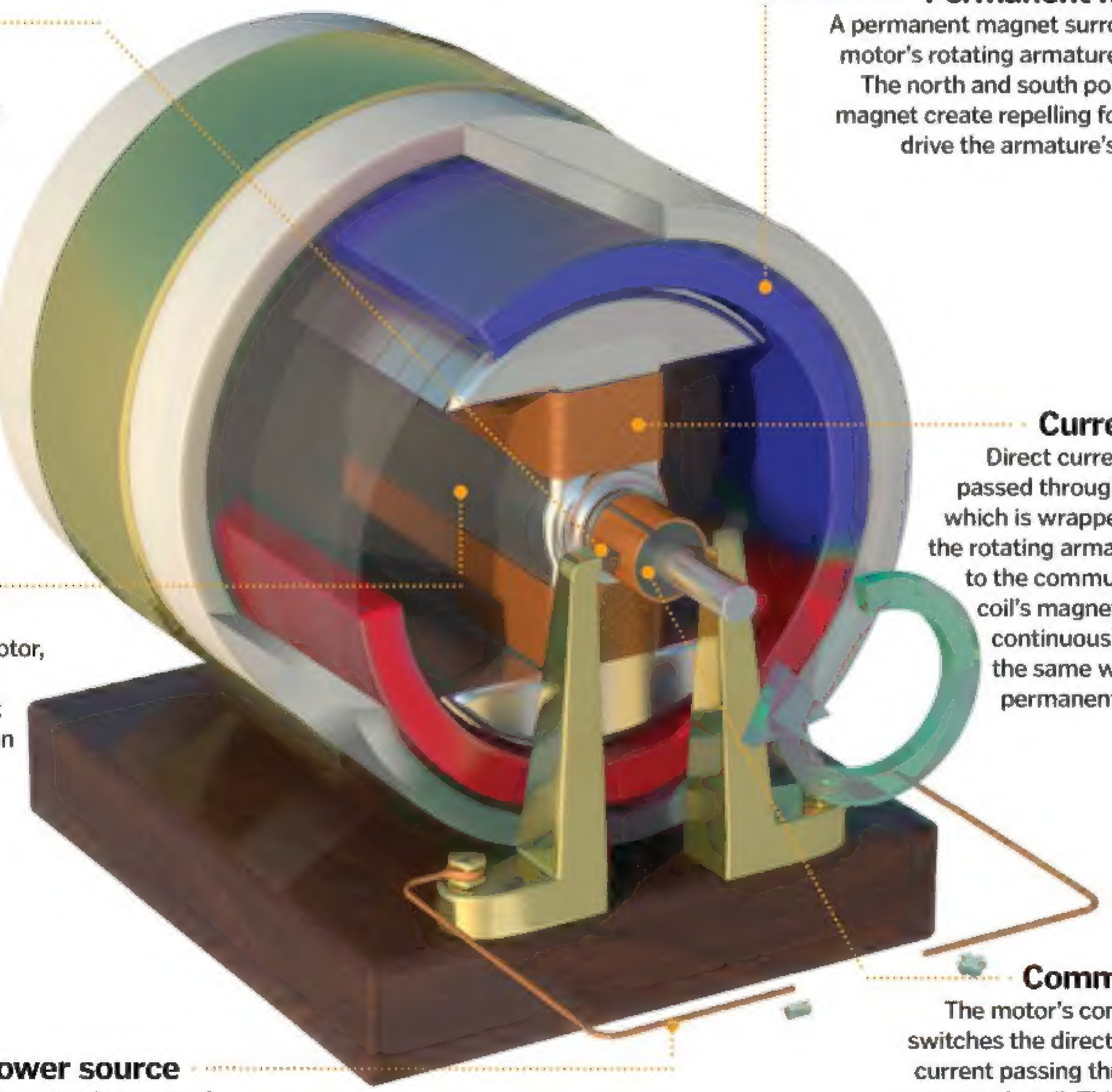
Electric motors are devices that, in simple terms, convert electricity – as delivered from one or more power sources – into mechanical energy through electromagnetism. This ability to generate workable mechanical power grants the electric motor broad appeal, driving all sorts of machines from cars to the hands of clocks.

The mechanical energy generated by electric motors is a result of the torque from the interaction of conductors carrying current and a magnetic field. The exact positioning of the conductors and the magnetic field differ depending on the type of motor – of which there are many (AC, DC, induction, etc) – but the principle remains the same: the interaction of the magnetic field with the winding currents generates a usable force within the motor.

As can be seen in the illustration, a basic electric motor consists of six key parts. The wire winding surrounding the motor's central armature is supplied with current, forcing unpaired electrons to align in the metal, merging their force and creating a coherent magnetic field. With the armature and windings now acting as an electromagnet, the surrounding permanent magnet – with its intrinsic north and south poles – forces the armature to spin at speed, with that kinetic energy harnessed for mechanical work.

DC motor cutaway

We highlight the core components of a direct-current electric motor



Top five electric motor uses

1 Cars
From the movement of simple components such as windscreen wipers, right through to the propulsion of all-electric vehicles like the Toyota Prius, electric motors are used to some extent in every automobile on Earth.

2 Appliances
It's amazing how many electric motors can be found in your very own home, with everything from food processors and electric whisks to vacuum cleaners relying on them.

3 Toys
Electric motors are now so cheap to make that they can even be incorporated into children's toys. Remote-control cars, animatronic models and action figures are all brought to life with them.

4 Gadgets
Electric toothbrushes, ceiling fans and automated window-cleaning robots are but a few of the increasingly diverse range of gadgets that incorporate electric motors.

5 Watches
The vast majority of quartz wristwatches, plus many analogue clocks, are powered by electric stepper motors, which regulate the movement of the hands.

DID YOU KNOW?

Faraday cinema

In 2003, the owners of Ward Anderson Cinemas in Ireland were ordered to remove the Faraday cage they'd installed to prevent mobile phones receiving signal during films. In France, these signal blockers are legal.

DID YOU KNOW? Cars need external aerials as radio waves cannot penetrate the metal chassis that acts as a Faraday cage

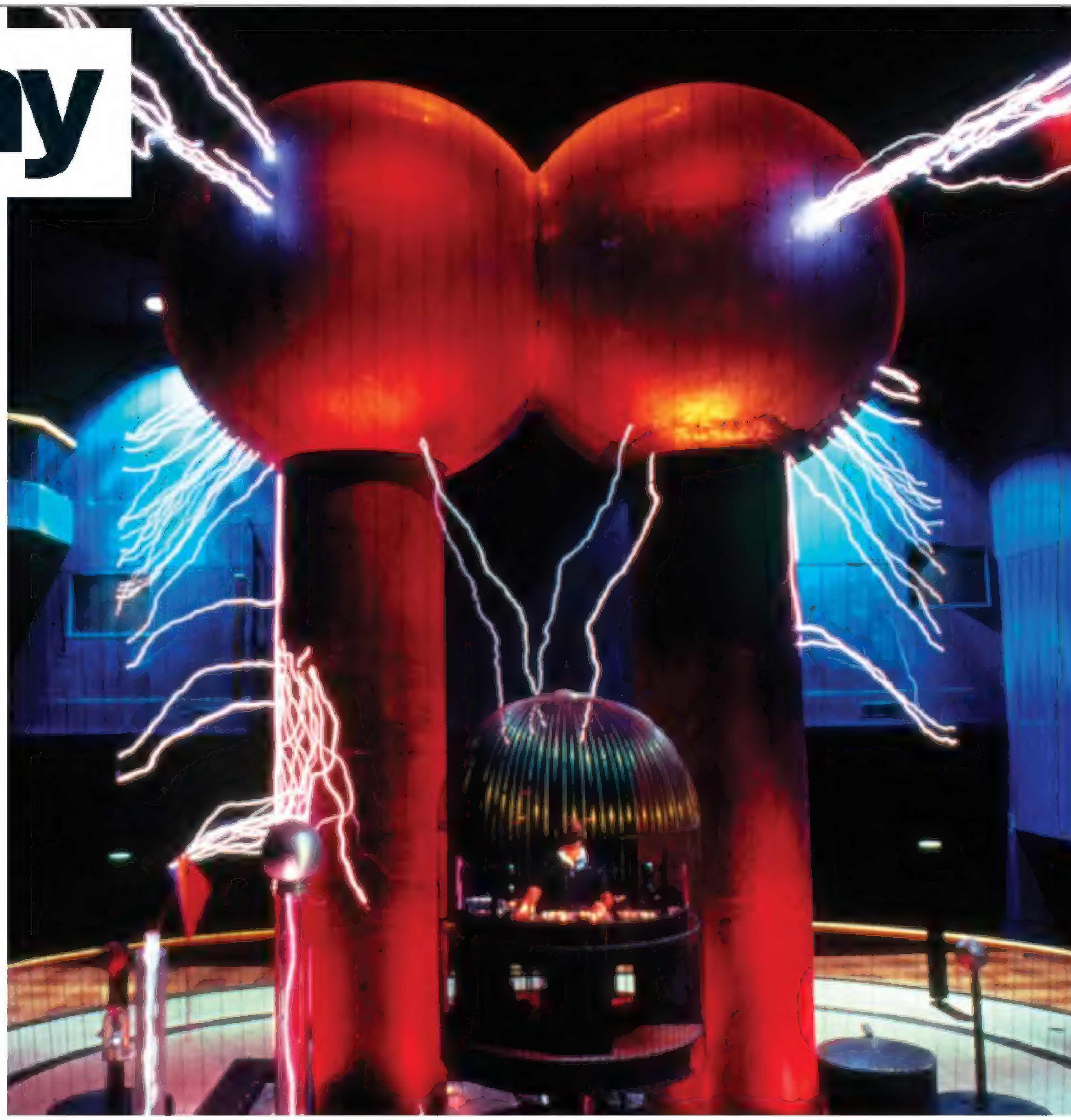
Faraday cages

What are these electromagnetic shields that protect us from electricity?

Faraday cages are all around us. A car can act as a Faraday cage and so can a plane and even some rooms. Because electromagnetic waves flow around the surface of such conductive materials as metal, rather than through them, the person in the Faraday cage remains protected from the electricity.

The metal exterior of the cage is full of positive and negative charges. Like a battery, the introduction of electricity moves the positive charges to one side of the cage and the negative to the other. These charges store the electricity, and this means that the interior of the cage is unaffected.

A Faraday cage can act as a shield against electromagnetic waves such as electricity, sound and radio waves. The Faraday cage can be a continuously enclosed piece of metal or a fine mesh with small, equally sized gaps.



© Science Photo Library

When lightning strikes your car

This shows how a car can protect passengers from a lightning strike